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(57) Abstract

Polynucleotide complexes are stabilized by adding a cryoprotectant compound and lyophilizing the resulting formulation. The lyophilized formulations are milled or sieved into a dry powder formulation which may be used to deliver the polynucleotide complex. Delivery of the polynucleotide to a desired cell tissue is accomplished by contacting the tissue with the powder to rehydrate it. In a preferred embodiment, a dry powder formulation is used to induce genetic modification of a patient's lung tissue.

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DRY POWDER FORMULATIONS OF POLYNUCLEOTIDE COMPLEXES

Relation to Other Applications

This application is a continuation-in-part of US Application Serial No. 08/092,200 filed July 14, 1993 and US Application Serial No. 07/913,669 filed July 14, 1992, which is a continuation-in-part of US Application Serial No. 07/864,876 filed April 3,1992, now abandoned.

Background Art

Molecular biologists have identified the chromosomal defects in a large number of human hereditary diseases, raising the prospects for cures using gene therapy. This emerging branch of medicine aims to correct genetic defects by transferring cloned and functionally active genes into the afflicted cells. Several systems and polymers suitable for the delivery of polynucleotides are known in the art. In addition, gene therapy may be useful to deliver therapeutic genes to treat various acquired and infectious diseases, autoimmune diseases and cancer.

Despite the usefulness of polynucleotide delivery systems, such systems are metastable and typically exhibit a decrease in activity when left in solution for longer than a few hours. For example, conventional cationic-lipid mediated gene transfer requires that the plasmid DNA and the cationic lipid be separately maintained and only mixed immediately prior to the gene transfer. Current attempts to stabilize polynucleotide complexes comprise speed-vac or precipitation methods, but they do not maintain activity over suitable time periods. Attempts to store polynucleotides in salt solutions lead to a loss of supercoil structure. If gene therapy protocols are to become widely used it will be necessary to have a stable and reproducible system for maintaining activity. This is of particular importance to pharmaceutical and commercial uses. Accordingly, there remains a need for means to stably maintain

polynucleotide compositions for extended periods of time. The present invention satisfies this and other needs.

Summary of the Invention

The invention comprises a method of stabilizing polynucleotide complexes by adding a cryoprotectant compound and lyophilizing the resulting formulation. Cryoprotectant compounds comprise carbohydrates, preferably lactose and sucrose, but also glucose, maltodextrins, mannitol, sorbitol, trehalose, and others. Betaines prolines, and other amino acids may also be useful. Preferably, the invention comprises DNA complexes cryoprotected with lactose at concentrations of about 1.25% to about 10% (w/vol). Conventional buffers may also be added to the mixture. The invention also comprises the lyophilized mixtures.

The lyophilized formulations may be stored for extended periods of time and then rehydrated prior to use. In an alternative embodiment, the lyophilized formulations may be milled or sieved into a dry powder formulation which may be used to deliver the polynucleotide complex. Once the powder contacts the desired tissue, it rehydrates, allowing delivery of the polynucleotide complex. In a preferred embodiment, a dry powder formulation is used to induce genetic modification of a patient's lung tissue.

Brief Description of the Drawings

FIG. 1 shows the effect of rehydration on the particle size distribution of lipid-polynucleotide complexes at varying concentrations of mannitol and lactose.

FIG. 2 compares the particle size distribution of lipid-polynucleotide complexes before lyophilization and after rehydration with and without cryoprotectant.

FIG. 3 shows the particle size distribution for various lipid-polynucleotide complexes before and after lyophilization.

FIG. 4 illustrates the effect of cryoprotectant on the zeta potential of lipid-polynucleotide complexes.

FIG. 5 is a graphical representation of gel electrophoresis results indicating the effect of lyophillization on complexation between lipid and polynucleotide.

FIGs. 6 and 7 show dose response curves of transfection efficiency comparing lyophillized and non-lyophillized lipid-polynucleotide complexes.

FIGs. 8-10 show the effect of lyophilization on transfection efficiency for lipid-polynucleotide complexes.

FIGs. 11-13 illustrate the effect of time on the transfection efficiency of lyophillized lipid-polynucleotide complexes.

FIG. 14 illustrates the effect of time on the transfection efficiency of rehydrated lipid-polynucleotide complexes.

FIG. 15 illustrates transfection using lyophilized dendrimer-polynucleotide complexes.

FIGs. 16-17 illustrate transfection using other lipid-polynucleotide complexes.

FIG. 18 shows expression of genetic information transferred using a dry powder formulation of a lyophilized polynucleotide complex.

FIG. 19-31 show various cationic lipids useful in forming lipid:polynucleotide complexes for lyophilization.

FIG. 32 shows predicted deposition sites in the respiratory tract for various size particles.

Detailed Description of the Drawings

The invention comprises stabilizing polynucleotide complexes by adding a cryoprotectant and lyophilizing the resulting mixture. Cryoprotectant compounds comprise carbohydrates, preferably lactose

and sucrose, but also glucose, maltodextrins, mannitol, sorbitol, trehalose, and others. It is believed the hydroxyl groups of the carbohydrates form hydrogen bonds with the polynucleotide complexes, displacing water and stabilizing the complexes. Useful ranges of cryoprotectant range from about 1.25% to about 10%, and particularly from 5-10%. Other suitable cryoprotectants include amino acids such as betaines and prolines that exhibit this hydrogen bonding stabilization effect.

A wide variety of polynucleotide complexes may be stabilized with the lyophillization techniques of this invention. The polynucleotide may be a single-stranded DNA or RNA, or a double-stranded DNA or DNA-RNA hybrid. Triple- or quadruple-stranded polynucleotides with therapeutic value are also contemplated to be within the scope of this invention. Examples of double-stranded DNA include structural genes, genes including operator control and termination regions, and self-replicating systems such as plasmid DNA, among others.

Single-stranded polynucleotides or "therapeutic strands" include antisense polynucleotides (DNA and RNA), ribozymes and triplex-forming oligonucleotides. In order to have prolonged activity, the therapeutic strand preferably has as some or all of its nucleotide linkages stabilized as non-phosphodiester linkages. Such linkages include, for example, phosphorothioate, phosphorodithioate, phosphoroselenate, or O-alkyl phosphotriester linkages wherein the alkyl group is methyl or ethyl, among others.

For these single-stranded polynucleotides, it may be preferable to prepare the complementary or "linker strand" to the therapeutic strand as part of the administered composition. The linker strand is usually synthesized with a phosphodiester linkage so that it is degraded after entering the cell. The "linker strand" may be a separate strand, or it may be covalently attached to or a mere extension of the therapeutic strand so that the therapeutic strand essentially doubles back and

hybridizes to itself. Alternatively, the linker strand may have a number of arms that are complementary so that it hybridizes to a plurality of polynucleotide strands.

The linker strand may also have functionalities on the 3′ or 5′ end or on the carbohydrate or backbone of the linker that serve as functional components to enhance the activity of the therapeutic strand. For example, the phosphodiester linker strand may contain a targeting ligand such as a folate derivative that permits recognition and internalization into the target cells. If the linker is attached to its complementary therapeutic strand that is composed of degradation-resistant linkages, the duplex would be internalized. Once inside the cell, the linker will be degraded, thereby releasing the therapeutic strand. In this manner, the therapeutic strand will have no additional functionalities attached and its function will not be impeded by non-essential moieties. This strategy can be applied to any antisense, ribozyme or triplex-forming polynucleotide and it is used to deliver anti-viral, anti-bacterial, anti-neoplastic, anti-inflammatory, anti-proliferative, anti-receptor blocking or anti-transport polynucleotides, and the like.

A separate linker strand may be synthesized to have the direct complementary sequence to the therapeutic strand and hybridize to it in a one-on-one fashion. Alternatively, the linker strand may be constructed so that the 5′ region of the linker strand hybridizes to the 5′ region of the therapeutic strand, and the 3′ region of the linker strand hybridizes to the 3′ region of the therapeutic strand to form a concatenate of the following structure.

```
5' ________ ________ ________
      3' ________ ________ ________
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This concatenate has the advantage that the apparent molecular weight of the therapeutic nucleic acids is increased and its pharmacokinetic properties and targeting ligand:therapeutic oligonucleotide ratio can be adjusted to achieve the optimal therapeutic effect. The linker strand

may also be branched and able to hybridize to more than one copy of the polynucleotide. Other strategies may be employed to deliver different polynucleotides concomitantly. This would allow multiple genes to be delivered as part of a single treatment regimen.

The polynucleotide complex may comprise naked polynucleotide such as plasmid DNA, multiple copies of the polynucleotide or different polynucleotides, or may comprise a polynucleotide associated with a peptide, a lipid including cationic lipids, a liposome or lipidic particle, a polycation such as polylysine, a branched, three-dimensional polycation such as a dendrimer, a carbohydrate or other compounds that facilitate gene transfer. Examples of useful polynucleotide compositions are found in U.S. Patent Applications Ser. No. 08/092,200, filed July 14, 1992, and Serial No. 07/913,669, filed July 14, 1993, which are hereby incorporated in their entirety by reference thereto.

<u>Results</u>

A 1:1 (w/w) liposome formulation containing the cationic lipid n-[1-(2,3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride [DOTMA](obtained from Syntex Inc. (U.S.A.)) and dioleoyl phosphatidylethanolamine (DOPE) was prepared by rehydration of a lipid film with subsequent extrusion under pressure using a 100 nm pore size polycarbonate membrane. Cryoprotectant, lipid and plasmid DNA, containing a CMV promoter and a β-galactosidase (CMV- gal) or chloroamphenicol acetyl transferase (CMV-CAT) reporter gene were mixed together under defined conditions to produce a 1:10:X (w:w:w) of pDNA/lipid/cryoprotectant formulation at a constant pDNA concentration of 250 μg/ml in a final volume of 1 ml, where X was 30, 100, 200, 250, 300, 500, 600, 750 and 100. This corresponds to a DNA:lipid charge ratio of 1:2. The cryoprotectants used were mannitol and lactose. The formulations were lyophillized using a programmable tray dryer (FTS Systems) at a product eutectic temperature of -30°C.

The lyophilized formulations were rehydrated at room temperature with water to a pDNA concentration of 250 μg/ml. After 30 minutes, the physicochemical properties of the lipid-pDNA complexes was determined by particle size analysis (Coulter N4MD), doppler electrophoretic light scattering (Coulter Delsa 440) and 1% agarose gel electrophoresis.

For *in vitro* studies, transfection efficiency of the pDNA-lipid-cryoprotectant formulations was studied on a variety of cell lines. HIG-82 (rabbit synoviocytes), C_2 C_{12} (mouse myoblasts) and HepG2 (human liver hepatoblastoma) cells were grown in F-12 Ham's, Dulbecco's Modified and in minimum essential Eagle's media (Gibco), respectively. All were supplemented with 10% fetal bovine serum (Gibco). Transfection was performed in the presence of serum containing media in 24-well plates at 40-60% cell density with 2 μg of pDNA per well. Cells were harvested and analyzed after 48 hours. A chemiluminescent reporter assay was performed according to TROPIX (Galacto-light) specifications. The percentage of β-galactosidase (LacZ) positive cells was determined by Commasie Blue protein assay. Relative light units (RLU) per μg of total protein and percentage of LacZ positive cells were used to assess transfection efficiency.

FIG. 1 shows the effect of rehydration on the particle size distribution of lipid-pDNA complexes at varying concentrations of mannitol and lactose. At cryprotectant:lipid ratios of 40:1 to 100:1 (corresponding to 4% and 10% formulations), complexes protected with lactose exhibit similar particle size distribution to non-lyophillized lipid-pDNA complexes. The complexes protected with mannitol exhibit larger particle size distributions. As shown in FIG. 2, lipid-pDNA complexes lyophillized without a cryoprotectant aggregate while lipid-pDNA complexes protected with lactose or sucrose do not aggregate following rehydration and exhibit particles size distributions substantially the same as before lyophillization.

FIG. 3 shows the particle size distribution before and after lyophillization for various lipid-pDNA complexes protected with 10% lactose. Lyophillization had little effect on particle size distribution regardless of the lipid composition or charge ratio.

FIG. 4 compares the zeta potential of lipid-pDNA complexes in the presence and absence of cryoprotectant. The presence of 10% lactose had substantially no effect on the zeta potential, except at a charge ratio of 1:1.

FIG. 5 is a graphical representation of gel electrophoresis results comparing lipid-pDNA complexes before and after lyophillization. Migration of the bands was generally unaffected following lyophillization and rehydration. This indicates the complexation between the lipid and the pDNA was not affected by the addition of 10% lactose.

FIGs. 6 and 7 show dose response curves of transfection efficiency comparing lyophillized and non-lyophillized lipid-pDNA complexes protected with 5% lactose, sucrose or glucose. At each pDNA concentration and for each cryoprotectant, transfection efficiency was either unaffected or improved by lyophillization. FIGs. 8-10 show the effect of lyophilization on transfection efficiency for lipid-pDNA complexes: FIG. 8 shows transfer of CMV-CAT at pDNA:DOTMA/DOPE ratios of 1:10 and 1:6 in C_2 C_{12} cells; FIG. 9 shows transfer of CMV- gal at pDNA:DOTMA/DOPE ratios of 1:10 and 1:6 in C_2 C_{12} cells; and FIG. 10 shows transfer of CMV- gal at pDNA:DOTMA/DOPE ratios of 1:10 and 1:6 in HepG2 cells. In each case transfection efficiency was improved by lyophillization.

FIGs. 11-13 show the transfection efficiency of stored DDAB:DOPE-DNA lyophilized complexes prepared at various conditions. Storage of the lyophillized lipid-pDNA did not decrease the transfection efficiency and some cases activity increased. In contrast, FIG. 14 shows the effect of storage time on the activity of rehydrated lipid-pDNA complexes. Transfection efficiency fell over a two week period.

This indicates the DNA compositions are stable only when in a lyophillized condition.

Other useful DNA complexes may be prepared as follows:

1. A gramicidin S-pDNA complex is formed with DNA encoding the luciferase gene. At room temperature, 20 μg of pDNA is diluted in 300 μl of 30 mM Tris HCL pH 8.5 in a polystyrene tube. Gramicidin S is diluted in Tris HCL 30 mM ph 8.5 buffer to a concentration of 2 mg/ml from a stock solution of 20 mg/ml in dimethyl sulfoxide. The diluted gramicidin S (20 μl/40 μg) is added to the DNA and quickly mixed. Then 175 μl of liposomes (equivalent to 175 nmoles of lipids) are slowly added with gentle mixing to the DNA-gramicidin S mixture. Lactose is added to a final concentration of 225 mM and the material placed in a vial. The formulation is frozen in a dry-ice ethanol bath and then lyophillized to produce a dry cake. The dry cake may be stored at 4°C and rehydrated to original volume.

2. A dendrimer-pDNA complex is formed with DNA encoding the luciferase gene. 6 μg of pDNA is diluted in 330 μl of 10 mM Hepes pH 7.3 in a polystyrene tube. The polycation sixth generation starburst dendrimer (2 - 160 μg) is diluted in Tris HCL 170 of HBS and added dropwise to the DNA and then gently mixed. Lactose is added to a final concentration of 225 mM and the material placed in a vial. The formulation is frozen in a dry-ice ethanol bath and then lyophillized to produce a dry cake. The dry cake may be stored at 4°C and rehydrated to original volume. FIG. 15 shows expression in cells transfected using a β-gal-dendrimer complex cryoprotected with lactose or sucrose and lyophilized at various temperatures.

Using methods similar to those above, other useful lipid-polynucleotide complexes may be cryoprotected and lyophilized. FIG. 16 illustrates transfection using lyophilized complexes of β-gal

associated with a 1:2 molar ratio of dimethyldioctadecylammonium bromide [DDAB]:dioleoyl phosphatidylethanolamine [DOPE] at varied charge ratios and varied doses. The complexes were cryoprotected at a pDNA:lactose weight ratio of 1:15. FIG. 17 shows transfection using lyophilized complexes of β-gal associated with a 1:1 molar ratio of [DOTAP]:dioleoyl phosphatidylethanolamine [DOPE] lyophilized with various concentrations of sucrose and frozen at various temperatures.

In other embodiments, other cryoprotectants may be used at similar concentration to the above examples. By lyophilizing in the minimal concentration of cryoprotectant, the formulations can be lyophilized and then rehydrated in a lesser volume to concentrate polynucleotide complex. The formulations may also include buffers that can be removed during lyophillization allows concentration of the preparation and subsequent rehydration to isotonicity. Suitable volatile buffers include triethanolamine-acetate, triethanolamine-carbonate, ammonium acetate, ammonium carbonate and other at concentrations from about 0.01 M to about 2 M. For example, a polynucleotide complex in a 1.25% sucrose solution and a 100 mM ammonium triethanolamine carbonate may be lyophilized and then rehydrated to 1/8 the original volume, maintaining the isotonicity of the rehydrated solution and concentrating the polynucleotide complex 8-fold.

Cationic lipids are useful in forming complexes to be cryoprotected and lyophilized. Conventional cationic lipids suitable for the practice of the invention include phosphatidylethanolamine [PE], dioleyloxy phosphatidylethanolamine [DOPE], n-[1-(2,3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride [DOTMA], dioleoylphosphatidylcholine [DOPC], 2,3-dioleyloxy-N-[2-(sperminecarboxyamido)ethyl]-N,N-dimethyl-1-propanaminium trifluoroacetate [DOSPA], [DOTAP], [DOGG], dimethyldioctadecylammonium bromide [DDAB], cetyldimethylethylammonium bromide [CDAB],

cetyltrimethylethylammonium bromide [CTAB], monooleoyl-glycerol [MOG], 1,2 dimyristyloxypropyl-3-dimehtyl-hydroxyethyl ammonium bromide [DMRIE], 1,2 dimyristoyl-sn-glycero-3-ethylphosphocholine [EDMPC], 1,2 dioleoyl-sn-glycero-3-ethylphosphocholine [EDOPC], 1 palmitoyl, 2 myristoyl-sn-glycero-3-ethylphosphocholine [EPMPC], cholesterol [Chol] and cationic bile salts. Other useful cationic lipids may be prepared in the following manners.

Spermine-5-carboxyglycine (N'-stearyl - N'-oleyl) amide tetratrifluoroacetic acid salt (JK-75) FIG. 19.

A *p*-nitrophenyl oleinate ester was prepared by a standard method. This active ester coupled with octadecylamine to give N-octadecyl oleic amide. Reduction of this amid by lithium aluminum hydride formed N-stearyl N-oleyl amine. A mixture of N-stearyl N-oleyl amine, N-butoxycarbonylglycine *p*-nitrophenyl ester, and triethylamine in dichloromethane was stirred at room temperature under argon for 24 h. The organic solution was extracted three times with 0.5 M sodium carbonate, followed by water, and then dried over sodium sulfate. The solvent was removed under reduced pressure, and the residue was purified by a silica gel flash column to give N- t-butoxycarbonylglycine (N'-stearyl - N'-oleyl) amide. This compound was deprotected by trifluoroacetic acid to give glycine (N'-stearyl - N'-oleyl) amide, which was then treated with tetra-t-butoxycarbonylspermine-5-carboxylic acid (prepared by the cyanoethylation of ornitine, followed by a hydrogenation and protection with Boc-on), dicyclohexylcarbodiimide and N-hudroxysuccinimide in dichloromethane in dark at room temperature under argon for 48 h. The solvent was removed under reduced pressure, and the residue was purified by a silica gel column. The desired compound was then deprotected in trifluoroacetic acid at room temperature for 10 min. The excess of acid was removed under vacuum to yield the spermine-5-carboxyglycine (N'-stearyl - N'-oleyl) amide tetra trifluoroacetic acid salt, as a light yellow wax. ^{1}H NMR (300

Mhz, CD_3OD) δ 5.20 (m, 2 H), 4.01 (s, 2 H), 3.87 (t, 1 H), 3.19-2.90 (m, 16 H), 2.01-1.27 (m, 21 H), 1.15 (broad s, 56 H), 0.76 (t, 6 H). LSIMS (NBA): m/e 805.8 for M^{4+} ($C_{49}H_{104}N_6O_2$)-3H^+.

Spermine-5-carboxyglycine (N'-stearyl- N'-elaidyl) amide tetratrifluoroacetic acid salt (JK-76). Fig 20.

Produced in a similar manner, by substituting for the appropriate starting material.

^{1}H NMR (300 MHz, CD_3OD): δ 5.24 (m, 2 H), 4.01 (s, 2 H), 3.87 (t, 1 H), 3.14-2.90 (m, 16 H), 2.01-1.21 (m, 21 H), 1.15 (broad s, 56 H), 0.76 (t, 6 H). LSIMS (NBA): m/e 805.8 for M^{4+} ($C_{49}H_{104}N_6O_2$)-3H^+.

Agmatinyl carboxycholesterol acetic acid salt (AG-Chol) FIG. 21.

Agmatine sulfate (100 mg, 0.438 mmol) was treated by tetramethylamonium hydroxide (158 mg, 0.876 mmol) in methanol (15 mℓ) for 1 h. The solvent was removed under reduced pressure. A suspension solution of the residue and cholesteryl chloroformate (197 mg, 0.438 mmol) in DMF (15 mℓ) was stirred at room temperature for 3 days. Filtration of the reaction mixture gave the crude product as a light yellow solid, which was purified by a silica gel column using chloroform-methanol-acetic acid (10:2:1) as eluent to yield the agmatinyl carboxycholesterol acetic acid salt as a white solid. ^{1}H NMR (300 MHz, CD_3OD): δ 5.27 (broad s, 1 H), 4.65 (broad m, 1 H), 3.06 (t, 2 H), 2.99 (t, 2 H), 2.21 (broad d, 2 H), 1.95-0.65 (m, 31 H), 1.80 (s, 4 H), 0.91 (s, 3 H), 0.82 (d, 3 H), 0.76 (s, 3 H), 0.74 (s, 3 H), 0.59 (s, 3 H). LSIMS (NBA): m/e 543.4 for M+ ($C_{33}H_{59}N_4O_2$).

Spermine-5-carboxy-β-alanine cholesteryl ester tetratrifluoroacetic acid salt (CAS) FIG. 22.

A solution of cholesteryl β-alanine ester (0.2 mmol), prepared with standard procedure, in dichloromethane (dry, 2 mℓ) was added into a solution of tetra-t-butoxycarbonylspermine-5-carboxylic acid N-hydroxysuccinimide ester (0.155 mmol) and 4-methylmorpholine (0.4 mℓ) in dichloromethane (5 mℓ). The reaction mixture was stirred at

room temperature under argon for 6 days. The solvent was removed under reduced pressure, and the residue was purified by a silica gel column using ethanol-dichloromethane (1:20) as eluent to give the desired product as a light yellow oil. This compound was treated with trifluoroacetic acid (0.5 mℓ) at room temperature under argon for 10 min. The excess trifluoroacetic acid was removed under reduced pressure to give spermine-5-carboxy-β-alanine cholesteryl ester tetratrifluoroacetic acid salt as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ 5.38 (m, 1 H), 4.60 (m, 1 H), 3.90 (t, J = 6.16, 1 H), 3.54 (m, 2 H), 3.04 (m, 10 H), 2.58 (t, J = 6.71, 2 H), 2.33 (d, J = 6.58, 2 H), 2.15 - 0.98 (m, 36 H), 1.04 (s, 3 H), 0.93 (d, J = 6.46, 3 H), 0.87 (d, J = 6.59, 6 H), 0.70 (s, 3 H). LSIMS (NBA): m/e 687.5 for M^{4+} $(C_{41}H_{80}N_5O_3)$-$3H^+$.

2,6-Diaminohexanoeyl β-alanine cholesteryl ester bistrifluoroacetic acid salt (CAL) FIG. 23.

Produced in a manner similar to CAS, by substituting for the appropriate starting material.

^1H NMR (300 MHz, $CDCl_3$): δ 8.10-7.62 (m, 7 H), 5.38 (broad s, 1 H), 4.60 (broad s, 1 H), 4.08 (broad s, 1H), 3.40 (broad s, 4 H), 3.02 (broad s, 4 H), 2.50 (broad s, 2 H), 2.26 (broad s, 2 H), 2.04 - 0.98 (m, 28 H), 1.04 (s, 3 H), 0.93 (d, J = 6.46, 3 H), 0.88 (d, J = 6.59, 6 H), 0.74 (s, 3 H). LSIMS (NBA): m/e 586.5 for M^{2+} $(C_{36}H_{65}N_3O_3)$-H^+.

2,4-Diaminobutyroyl β-alanine cholesteryl ester bistrifluoroacetic acid salt (CAB) Fig. 24.

Produced in a manner similar to CAS, by substituting for the appropriate starting material.

^1H NMR (300 MHz, $CDCl_3$): δ 8.34-8.06 (m, 7 H), 5.38 (broad s, 1 H), 4.60 (broad s, 1 H), 4.30-3.20 (broad m, 11 H), 2.50- 0.98 (m, 36 H), 1.04 (s, 3 H), 0.93 (d, J = 6.46, 3 H), 0.88 (d, J = 6.59, 6 H), 0.74 (s, 3 H). LSIMS (NBA): m/e 558.5 for M^{2+} $(C_{34}H_{61}N_3O_3)$-H^+.

N, N-Bis (3-aminopropyl)-3-aminopropionyl β-alanine cholesteryl ester tristrifluoroacetic acid salt (CASD) FIG. 25.

Cyanoethylation of the β-alanine with acrylnitrile in the presence of 1,4-diazabicyclo [2.2.2] octane at 90 °C for 15 h gave the N,N-bis(2-cyanoethyl)-3-aminopropionic acid. Hydrogenation of the N,N-bis(2-cyanoethyl)-3-aminopropionic acid in ethanol-water (1:1) using Raney nickel as catalyst yielded the N,N-bis(3-aminoethyl)-3-aminopropionic acid. The amino groups of this compound was protected by 2-(t-butoxycarbonyloxylmino)-2-phenylacetonitrile in acetone-water (4:1) to give N,N-bis (t-butoxycarbonyl-3-animoethyl)-3-aminopropionic acid. This compound was activated by chloroacetonitrile and triethylamine to form cyanomethyl N,N-bis (t-butoxycarbonyl-3-animoethyl)-3-aminopropionate. A solution of the cyanomethyl ester and cholesteryl β-alanine ester in chloromethane was stirred in dark at room temperature under argon for 10 days. The solvent was removed under reduced pressure, and the residue was purified by a silica gel column using methanol-chloroform (1:10) as eluant to yield the N,N-bis (t-butoxycarbonyl-3-aminoethyl)-3-aminopropionoyl β-alanine cholesteryl ester. Treatment of this compound with trifluoroacetic acid formed N, N-bis (3-aminopropyl)-3-aminopropionoyl β-alanine cholesteryl ester tristrifluoroacetic acid salt. ^{1}H NMR (300 MHz, CD_3OD-$CDCl_3$ 1:1): δ 8.13 (broad s, 3 H), 5.78 (broad s, 3 H), 5.38 (broad s, 1 H), 5.18 (s, 1H), 4.74 (s, 1 H), 4.60 (broad s, 1 H), 3.54-3.04 (m, 10 H), 2.80 (t, J=6.60, 2 H), 2.73 (t, J= 6.54, 2 H), 2.53(t, J=6.42, 2 H), 2.32(d, J = 6.58, 2 H), 2.15 - 0.98 (m, 30 H), 1.04 (s, 3 H), 0.91 (d, J = 6.42, 3 H), 0.86 (d, J = 6.58, 6 H), 0.70 (s, 3 H). LSIMS (NBA): m/e 643.5 for M^{3+} ($C_{39}H_{73}N_4O_3$)-$2H^+$.

[N, N-Bis(2-hydroxyethyl)-2-aminoethyl]aminocarboxy cholesteryl ester (JK-154) FIG. 26.

A solution of cholesteryl chloroformate (0.676 g, 1.51 mmol) and ethelenediamine (4 mℓ) in chloroform (10 mℓ) was stirred in dark at room temperature under argon for 16 h. The solvent and excess of ethylendiamine were removed under reduced pressure, and the residue was purified by a silica gel column using CH_3OH-$CHCl_3$ (NH_3) (v/v, 0-20 %) as eluent to give ethylendiamine cholesterylcarboxymonoamide as a white solid. A mixture of this compound (80 mg, 0.17 mmol), 2-hydroxyethylbromide (2 mℓ) and triethylamine (2 mℓ) was stirred in dark at room temperature under argon for 14 days. The excess of triethylamine and 2-hydroxyethylbromide were removed under reduced pressure, and the residue was purified by a silica gel column using CH_3OH-$CHCl_3$ (v/v, 1:3) as eluent to give the 2-[N, N-Bis(2-hydroxyethyl) aminoethyl] amino carboxy cholesteryl ester as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ LSIMS (NBA): m/e 643.5 for M^{3+} ($C_{39}H_{73}N_4O_3$)-$2H^+$.

Carnitine ester lipids

Carnitine lipids are synthesized by acylating the hydroxy group of L-carnitine by standard methods to create the monoacyl carnitine. The carboxy group of the carnitine is modified with a second acyl chain to make a phospholipid analog with a single quarternary ammonium cationic group. The other carnitine stereoisomers D- and D,L- are suitable, but the L-form is preferred. The acyl chains are between 2 and 30 carbons and may be saturated or unsaturated, with from 1 to 6 unsaturated groups in either the cis or trans configuration. The acyl chains may also contain iso forms. A preferred form comprises the oleoyl group, a chain 18 carbons long with a cis unsaturated bond at C_9. This generic carnitine ester is shown in FIG. 27. Presently preferred carnitine esters follow.

Stearyl carnitine ester

A solution of DL-carnitine hydrochloride (1.0 g, 5.05 mmol) and sodium hydroxide (0.303 g, 7.58 mmol) in ethanol (15 mℓ) was stirred at room

temperature for 2 h. The formed white precipitate (NaCl) was removed by filtration, and the solvent was evaporated under reduced pressure to give a white solid, carnitine inner salt. A suspension of the carnitine inner salt and 1-iodooctadecane (2.31 g, 6.06 mmol) in DMF-dioxane (3 : 5, 40 mℓ) was heated with an oil-bath at 120 °C under Ar_2 for 4 h. The solvent was removed by rotavapor and vacuum, and the residue was chromatographied with silica gel column using CH_3OH-CH_3Cl as eluant to give 2.22 g (81 %) of stearyl carnitine ester as a white solid: ^1H NMR ($CDCl_3$) δ 4.79 (m, 1 H), 4.43 (d, J =5.3, 1 H), 4.09(t, J =6.9, 2 H), 4.03 (d, J =13.o, 1 H), 3.67 (dd, J =10.3, 13.3, 1 H), 3.51 (s, 9 H), 2.79 (dd, J =5.7, 17.0, 1 H), 2.66 (dd, J = 7.0, 17.1, 1 H), 1.80-1.60 (m, 4 H), 1.26 (broad s, 28 H), 0.88 (t, J = 6.6, 3 H). LSIMS (NBA): m/e 414.4 for $C_{25}H_{52}NO_3$ (cation).

Palmityl carnitine ester

With the procedure used for the preparation of stearyl carnitine ester, 0.77 g (4.77 mmol) of carnitine inner salt and 2.52 g (7.15 mmol) of 1-iodohexadecane to give 1.59 g (65 %) of palmityl carnitine ester as a white solid: ^1H NMR ($CDCl_3$) δ 4.78 (m, 1 H), 4.44 (d, J =5.4, 1 H), 4.09 (t, J =6.9, 2 H), 3.65 (dd, J =10.2, 13.3, 1 H), 3.58 (d, J =5.1, 1 H), 3.51 (broad s, 9 H), 2.80 (dd, J =5.7, 17.2, 1 H), 2.66 (dd, J =7.1, 17.1, 1 H), 1.65 (broad m, 4 H), 1.26 (broad s, 24 H), 0.88 (t, J =0.66, 3 H). LSIMS (NBA): m/e 386.2 for $C_{23}H_{48}NO_3$ (cation).

Myristyl carnitine ester

With the procedure used for the preparation of stearyl carnitine ester, 0.77 g (4.77 mmol) of carnitine inner salt and 2.31 g (7.15 mmol) of 1-iodotetradecane gave 1.70 (74 %) of myristyl carnitine ester as a white solid: ^1H NMR ($CDCl_3$) δ 4.79 (m, 1 H), 4.43 (d, J =5.3, 1 H), 4.09(t, J =6.9, 2 H), 4.03 (d, J =13.o, 1 H), 3.67 (dd, J =10.3, 13.3, 1 H), 3.51 (s, 9 H), 2.79 (dd, J =5.7, 17.0, 1 H), 2.66 (dd, J = 7.0, 17.1, 1 H), 1.80-1.60 (m, 4 H), 1.26 (broad s, 20 H), 0.88 (t, J = 6.6, 3H). LSIMS (NBA): m/e 358.1 for $C_{21}H_{44}NO_3$ (cation).

Stearyl stearoyl carnitine ester chloride salt (SSCE) FIG. 28.

A solution of DL-carnitine hydrochloride (1.0 g, 5.05 mmol) and sodium hydroxide (0.303 g, 7.58 mmol) in ethanol (15 mℓ) was stirred at room temperature for 2 h. The formed white precipitate (NaCl) was removed by filtration, and the solvent was evaporated under reduced pressure to give a white solid, carnitine inner salt. A suspension of the carnitine inner salt and 1-iodooctadecane (2.31 g, 6.06 mmol) in DMF-dioxane (3 : 5, 40 mℓ) was heated with an oil-bath at 120 °C under argon for 4 h. The solvent was removed under reduced pressure, and the residue was purified by a silica gel column using CH_3OH-CH_3Cl (v/v, 0-10%) as eluent to give the stearyl carnitine ester as a white solid. A solution of a fresh prepared stearic anhydride (1.94 g, 3.52 mmol), stearyl carnitine ester (0.953 g, 1.76 mmol) and 4-dimethylaminopyridine (0.429 g, 3.52 mmol) in CH_3Cl (dry, 15 mℓ) was stirred at room temperature under argon for four days. The solvent was removed under reduced pressure, and the residue was washed twice by cold diethyl ether. The solid was chromatographied on a silica gel column using MeOH-$CHCl_3$ (v/v, 1:5) as eluent to give the stearyl stearoyl carnitine ester iodide. The iodide was exchanged by chloride with an anion exchange column to give the stearyl stearoyl carnitine ester chloride as a white solid. ^1H NMR (300 MHz, $CDCl_3$) δ 5.67 (q, 1 H), 4.32 (d, 1 H), 4.07 (m, 3 H), 3.51 (s, 9 H), 2.82 (t, 2 H), 2.33 (t, 2 H), 1.59 (broad m, 4 H), 1.25 (broad s, 58 H), 0.88 (t, 6 H). LSIMS (NBA): m/e 680.6 for M^+ ($C_{43}H_{86}NO_4$). Anal. Calcd for $C_{43}H_{86}ClNO_4.H_2O$: C, 70.30; H, 12.07; N, 1.91. Found: C, 70.08; H, 12.24; N, 1.75.

L-Stearyl Stearoyl Carnitine Ester (L-SSCE) was prepared with the same procedure using L-carnitine as starting material. Analytical data are same as DL-SSCE.

Stearyl oleoyl carnitine ester chloride (SOCE) FIG. 29.

Prepared in a manner similar to SSCE, by substituting the appropriate starting material.

^{1}H NMR (300 MHz, $CDCl_3$): δ 5.67 (q, 1 H), 5.35 (m, 2 H), 4.32 (d, 1 H), 4.08 (m, 3 H), 3.48 (s, 9 H), 2.83 (dd, 2 H), 2.34 (dd, 2 H), 2.02 (broad m, 4 H), 1.26 (broad m, 54 H), 0.88 (t, 6 H). LSIMS (NBA): m/e 678.7 for M+ ($C_{43}H_{84}NO_4$). Anal. Calcd for $C_{43}H_{84}ClNO_4.H_2O$: C, 70.50; H, 11.83; N, 1.91. Found: C, 70.77; H, 12.83; N, 1.93.

Palmityl palmitoyl carnitine ester chloride (PPCE) FIG. 30.

Prepared in a manner similar to SSCE, by substituting the appropriate starting material.

^{1}H NMR (300 MHz, $CDCl_3$): δ 5.67 (q, 1 H), 4.33 (d, 1 H), 4.07 (m, 3 H), 3.51 (s, 9 H), 2.82 (t, 2 H), 2.33 (t, 2 H), 1.59 (broad m, 4 H), 1.25 (broad s, 58 H), 0.99 (t, 6 H). LSIMS (NBA): m/e680.6 for M^+ ($C_{43}H_{78}NO_4$). Anal. Calcd for $C_{39}H_{78}ClNO_4.H_2O$: C, 69.04; H, 11.88; N, 2.06. Found: C, 69.31; H, 11.97; N, 2.37.

Myristyl myristoyl carnitine ester chloride (MMCE) FIG. 31.

Prepared in a manner similar to SSCE, by substituting the appropriate starting material.

^{1}H NMR (300 MHz, $CDCl_3$): δ 5.67 (q, 1 H), 4.32 (d, 1 H), 4.07 (m, 3 H), 3.50 (s, 9 H), 2.82 (t, 2 H), 2.33 (t, 2 H), 1.61 (broad m, 4 H), 1.26 (broad s, 42 H), 0.88 (t, 6 H). LSIMS (NBA): m/e 568.6.7 for M+ ($C_{35}H_{70}NO_4$). Anal. Calcd for $C_{35}H_{70}ClNO_4.1/2H_2O$: C, 68.53; H, 11.67; N, 2.28. Found: C, 68.08; H, 11.80; N, 2.21.

L-Myristyl myristoyl carnitine ester chloride (L-MMCE) was prepared with the same procedure using L-carnitine as starting material. Analytical data are same as DL-MMCE. m.p. 157 °C (decomposed).

These results demonstrate a number of the benefits exhibited by lyophilized polynucleotide complexes. The freeze-drying process does not substantially effect the physicochemical properties of the polynucleotide complexes yet confer stability over protracted periods of time. The formulations allow preparation of high concentrations of

complex. For cationic lipids at least, lyophilization with certain cryoprotectants followed by rehydration results in improved transfection efficiencies compared to non-lyophilized controls. It is believed that the process stabilizes the polynucleotide-cation interaction, generating complexes of defined particle size following rehydration.

Dry Powder Formulations

Lyophillized polynucleotide complexes may be sieved or milled to produce dry powder formulations (DPF). The powder may be used to generate a powder aerosol for delivering the polynucleotide to the lung. A current limitation of aerosol delivery is that high concentrations of DNA must be used in order to achieve sufficient gene transfer. At these concentrations, the polynucleotide complexes aggregate. The DPF permits use of high concentrations of polynucleotide. The powder is diluted when dispersed into the lung so that risk of aggregation is minimized. Once in contact with the lung tissue, the powder will rehydrate and regain its activity.

In a first example, plasmid CMV-CAT DNA was complexed as described above with a DOTMA:DOPE lipid formulation at a ratio of 1:10 (w/w). As a control, naked pCMV-CAT may be cryoprotected. The cryoprotectant mannitol was added at pDNA:mannitol ratios of 1:100 and 1:500 (w/w). The formulations were lyophillized at a product eutect temperature of 30°C to form a dry cake and retained under vacuum. Control instillation formulations were rehydrated to provide physicochemical and transfective comparison to the DPFs. The lyophillized product was sieved using a brass U.S.A. Standard 38 μm Sieve Apparatus in a dry glove box. The complex powder was sieved into crystalline lactose (Pharmatose) to produce a 1:6 (w/w) powder:Pharmatose concentration. Pharmatose acts as a carrier for the DPF formulations. In other embodiments, a carrier may not be

desirable. Resulting exemplary pCMV-CAT concentrations for the DPFs are as follows:

1:0:100 (w/w/w) pDNA:lipid:mannitol	-	1.41 μg/mg
1:10:100 (w/w/w) pDNA:lipid:mannitol	-	1.29 μg/mg
1:0:500 (w/w/w) pDNA:lipid:mannitol	-	0.29 μg/mg
1:10:500 (w/w/w) pDNA:lipid:mannitol	-	0.28 μg/mg

The DPFs were tested for *in vivo* activity by treating mice with the formulations and a Pharmatose control, harvesting the lung and trachea and assessing CAT expression. 10 mg of DPF were delivered via direct intratracheal injections using a Penn-Century Delivery device, resulting in approximately 50% delivery. FIG. 18 shows that the CMV-CAT DPF delivered at various doses resulted in CAT expression in the lung cells.

In another example, similar DPFs were produced using a jet milled using a high speed shear mixer. A 1:10:100 (w/w/w) pDNA/lipid/mannitol complex was jet milled at a grinding pressure of 130 psi and a feed rate of 40 mg/ml. The resulting powder had a nearly monodisperse particle size distribution of 80% at 3.2 - 3.8 μm as determined by laser light scattering. Electron microscopy revealed that many particles were <1 μm. Jet milling at a grinding pressure of 80 psi and a feed rate of 700 mg/ml resulted in a nearly monodisperse particle size distribution of 80% at 3.7 - 4.8 μm. In comparison, a sieved DPF showed a slight increase in the percentage of particles <10 μm. Prior to jet milling, the DPF was polydisperse with a particle size distribution of 80% at 5 -27 μm.

DPFs may be used to deliver genes useful in the treatment of a lung disease. For example, complexes formed with DNA encoding for cystic fibrosis transmembrane conductance regulator (CFTR) may be used to treat cystic fibrosis. In similar manner, other lung diseases such as alpha-1-antitrypsin deficiency, asthma, pulmonary embolism, adult respiratory distress syndrome, pulmonary hypertension, chronic obstructive pulmonary disease, lung cancer, pulmonary fibrosis,

pulmonary microbial infections, pulmonary pseudomonas infections, pulmonary inflammatory disorders, chronic bronchitis, pulmonary viral infections, respiratory syncitial virus, lung tissue rejection, emphysema and pulmonary allergic disorders could be treated. In preferred embodiments, the average particle size of the DPF is controlled to skew the deposition of the particles in desired region of the respiratory system. Although the deposition of particles is affected by a number of factors, including environmental conditions, particle characteristics, respiratory tract characteristics and breathing pattern characteristics, predictive models are possible. FIG. 32 shows the deposition fraction at various compartments of the respiratory tract for inhaled aerosols as a function of particle size. DPFs should generally have an average particle size of less than about 100 μm, preferably less than about 10 μm, and particularly preferably less than about 1 μm for treatment of the lung.

In other embodiments, DPFs are useful for the treatment of skin diseases. DPFs could be also be formulated as a pill for ingestion or as a suppository allowing for treatment of a wide range of internal or systemic conditions.

What is claimed is:

1. A method for delivering a polynucleotide to a cell comprising the steps of adding a cryoprotectant to a polynucleotide complex, lyophilizing the complex, contacting the cell with the complex and producing a dry powder formulation having an average particle size from the lyophilized complex.

2. The method of claim 1, wherein the step of contacting the cell with the complex comprises aerosolizing the powder and delivering it to a patient's respiratory tract.

3. The method of claim 2, wherein the step of producing the dry powder formulation comprises adjusting the average particle size to selectively deliver the aerosolized powder to a desired region of the patient's respiratory tract.

4. The method of claim 2, wherein the polynucleotide composition is useful for treating a condition selected from the group consisting of cystic fibrosis, alpha-1-antitrypsin deficiency, asthma, pulmonary embolism, adult respiratory distress syndrome, pulmonary hypertension, chronic obstructive pulmonary disease, lung cancer, pulmonary fibrosis, pulmonary microbial infections, pulmonary pseudomonas infections, pulmonary inflammatory disorders, chronic bronchitis, pulmonary viral infections, respiratory syncitial virus, lung tissue rejection, emphysema and pulmonary allergic disorders.

5. A composition for delivering a polynucleotide to a cell, comprising a lyophilized formulation of a polynucleotide complex and a cryoprotectant in a dry powder formulation having an average particle size.

6. The composition of claim 5, wherein the average particle size is not greater than about 100 μm.

7. The composition of claim 6, wherein the average particle size is not greater than about 10 μm.

8. The composition of claim 7, wherein the average particle size is not greater than about 1 μm.

9. A method for treating a polynucleotide complex comprising the steps of adding a cryoprotectant to the polynucleotide complex, lyophilizing the polynucleotide complex and producing a dry powder formulation from the lyophilized complex.

10. The method of claim 9, wherein the step of producing a dry powder formulation comprises sieving the lyophilized complex.

11. The method of claim 9, wherein the step of producing a dry powder formulation comprises jet milling the lyophilized complex.

12. The method of claim 9, wherein the step of producing a dry powder formulation comprises producing a powder with an average particle size of not greater than about 100 μm.

13. A method for gene therapy comprising contacting a eukaryotic cell with the composition of claim 1.

14. The method of claim 13 comprising contacting the cell under in vivo conditions.

15. The method of claim 13 comprising contacting the cell under in vitro conditions.

16. The method of claim 14 comprising contacting a mammalian cell.

17. The method of claim 14 comprising contacting a human cell.

18. The method of claim 15 comprising contacting a mammalian cell.

19. The method of claim 15 comprising contacting a human cell.

20. The composition of claim 5, wherein the polynucleotide complex comprises a lipid-polynucleotide complex wherein the lipid is selected from the group consisting of phosphatidylethanolamine [PE], phosphatidyl choline [PC], dioleyloxy phosphatidylethanolamine [DOPE], n-[1-(2,3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride [DOTMA], dioleoylphosphatidylcholine [DOPC], 2,3-dioleyloxy-N-[2-(sperminecarboxyamido)ethyl]-N,N-dimethyl-1-pro panaminium trifluoroacetate [DOSPA], [DOTAP], [DOGG], spermine-5-carboxyglycine(N'-stearyl -N'-stearyl)amide tetra-trifluoroacetic acid salt [DOGS], 1,2 dimyristyloxypropyl-3-dimehtyl-hydroxyethyl ammonium bromide [DMRIE], 1,2 dimyristoyl-sn-glycero-3-ethylphosphocholine [EDMPC], 1,2 dioleoyl-sn-glycero-3-ethylphosphocholine [EDOPC], 1 palmitoyl, 2 myristoyl-sn-glycero-3-ethylphosphocholine [EPMPC] dimethyldioctadecylammonium bromide [DDAB], cetyldimethylethylammonium bromide [CDAB],

cetyltrimethylethylammonium bromide [CTAB],], monooleoyl-glycerol [MOG], cholesterol [Chol], cationic bile salts, spermine-5-carboxyglycine (N'-stearyl -N'-oleyl) amide tetratrifluoroacetic acid salt [JK-75], spermine-5-carboxyglycine (N'-stearyl-N'-elaidyl) amide tetratrifluoroacetic acid salt [JK-76], agmatinyl carboxycholesterol acetic acid salt [AG-Chol], spermine-5-carboxy-β-alanine cholesteryl ester tetratrifluoroacetic acid salt [CAS], 2,6-diaminohexanoeyl β-alanine cholesteryl ester bistrifluoroacetic acid salt [CAL], 2,4-diaminobutyroyl β-alanine cholesteryl ester bistrifluoroacetic acid salt [CAB], N, N-bis (3-aminopropyl)-3-aminopropionyl β-alanine cholesteryl ester tristrifluoroacetic acid salt [CASD], [N, N-bis(2-hydroxyethyl)-2-aminoethyl]aminocarboxy cholesteryl ester [JK-154], carnitine ester lipids, stearyl carnitine ester, myristyl carnitine ester, stearyl stearoyl carnitine ester chloride salt [SSCE], L-stearyl stearoyl carnitine ester [L-SSCE], stearyl oleoyl carnitine ester chloride [SOCE], palmityl palmitoyl carnitine ester chloride [PPCE], myristyl myristoyl carnitine ester chloride [MMCE] and L-myristyl myristoyl carnitine ester chloride [L-MMCE].

FIG. 1

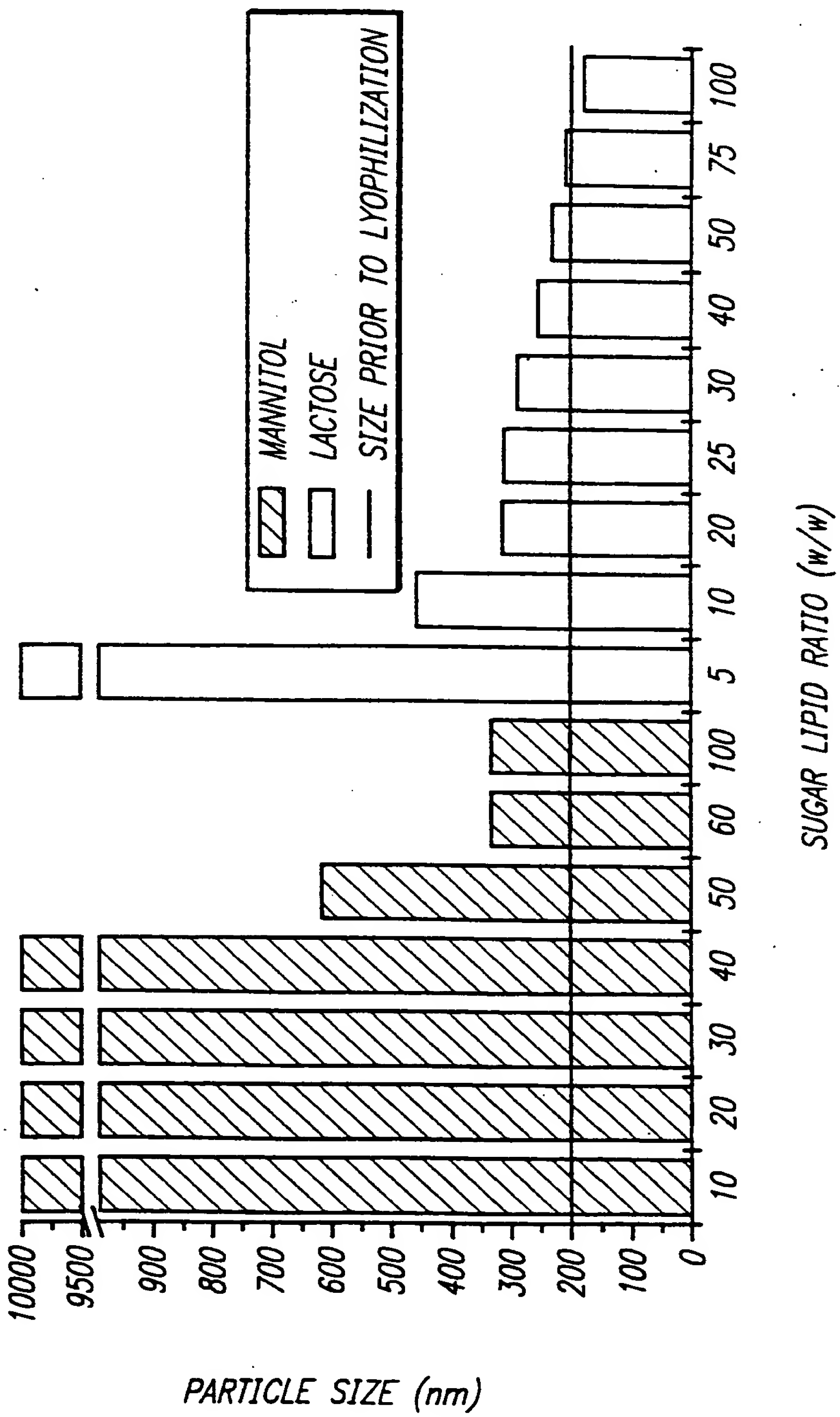
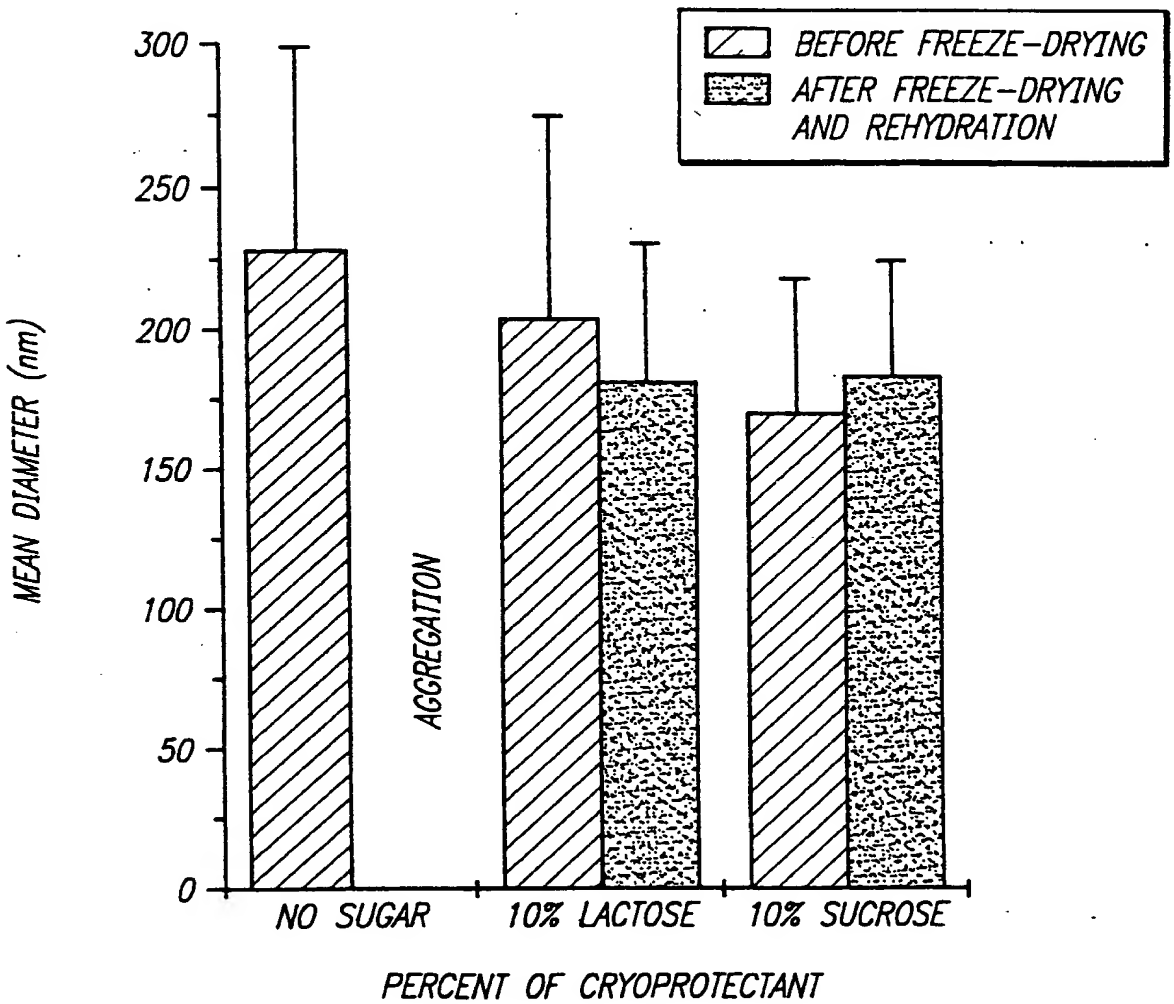

MANNITOL
LACTOSE
SIZE PRIOR TO LYOPHILIZATION
PARTICLE SIZE (nm)
10000
9500
900
800
700
600
500
400
300
200
100
0
SUGAR LIPID RATIO (w/w)
10
20
30
40
50
60
100
5
10
20
25
30
40
50
75
100

FIG. 2



* DNA/DOTMA:DOPE RATIO = 1:10 w/w
* LIPOSOME:SUGAR RATIO = 1:100 w/w
* DNA CONCENTRATION = 100μg/mL
* SIMILAR RESULTS WERE OBTAINED WITH 5% CRYOPROTECTANT.

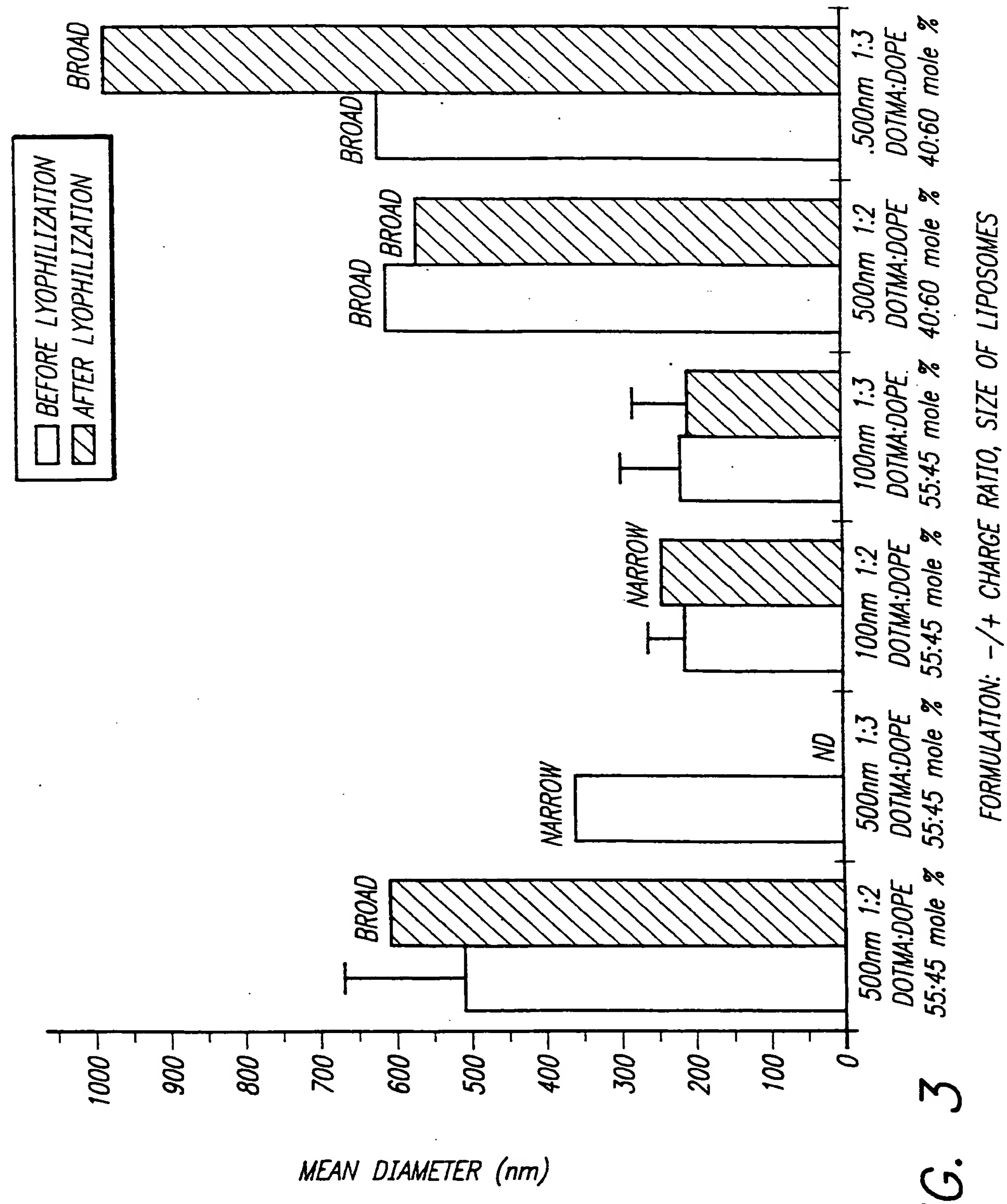
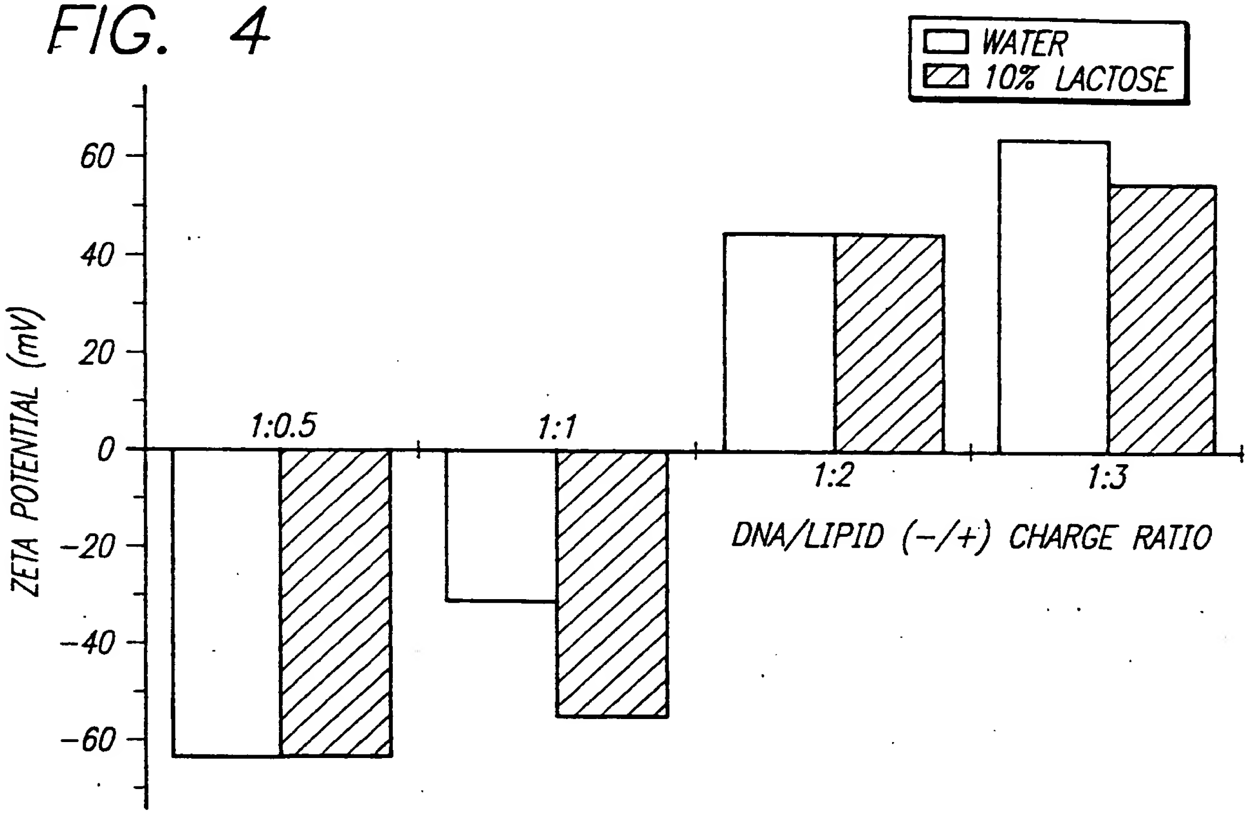

BEFORE LYOPHILIZATION
AFTER LYOPHILIZATION
MEAN DIAMETER (nm)
0
100
200
300
400
500
600
700
800
900
1000
BROAD
NARROW
ND
NARROW
BROAD
BROAD
BROAD
BROAD
500nm 1:2 DOTMA:DOPE 55:45 mole %
500nm 1:3 DOTMA:DOPE 55:45 mole %
100nm 1:2 DOTMA:DOPE 55:45 mole %
100nm 1:3 DOTMA:DOPE 55:45 mole %
500nm 1:2 DOTMA:DOPE 40:60 mole %
500nm 1:3 DOTMA:DOPE 40:60 mole %
FORMULATION: −/+ CHARGE RATIO, SIZE OF LIPOSOMES

FIG. 3

FIG. 4


WATER
10% LACTOSE
ZETA POTENTIAL (mV)
60
40
20
0
-20
-40
-60
1:0.5
1:1
1:2
1:3
DNA/LIPID (-/+) CHARGE RATIO

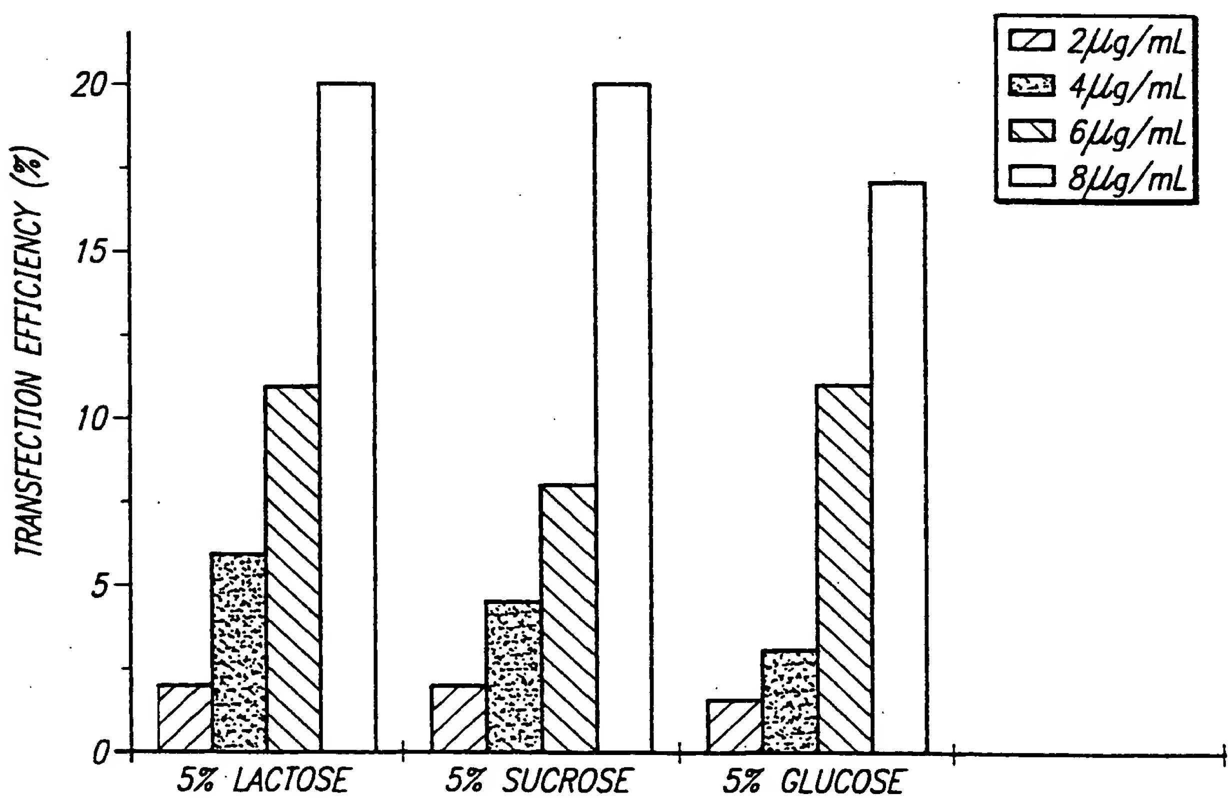

2μg/mL
4μg/mL
6μg/mL
8μg/mL
TRANSFECTION EFFICIENCY (%)
20
15
10
5
0
5% LACTOSE
5% SUCROSE
5% GLUCOSE

FIG. 6

Fig 5 1% Agarore gel electrophoresis of DNA/lipid complex in the presence of 10% lactose:

Before lyophilization
Lane 1: 1:2 -/+, DOTMA:DOPE,55:45 mol%, 100nm
Lane 2: 1:2 -/+, DOTMA:DOPE,40:60 mol%, 100nm
Lane 3 1:3 -/+, DOTMA:DOPE,40:60 mol%, 100nm
Lane 4: 1:0.5 -/+, DOTMA:DOPE,55:45 mol%, 100nm
Lane 5: Free DNA
Lane 6: Molecular standard

After lyophilization and rehydration
Lane 7: 1:2 -/+, DOTMA:DOPE,55:45 mol%, 100nm
Lane 8: 1:2 -/+, DOTMA:DOPE,40:60 mol%, 100nm
Lane 9: 1:3 -/+, DOTMA:DOPE,40:60 mol%, 100nm
Lane 10: 1:0.5 -/+, DOTMA:DOPE,55:45 mol%, 100nm

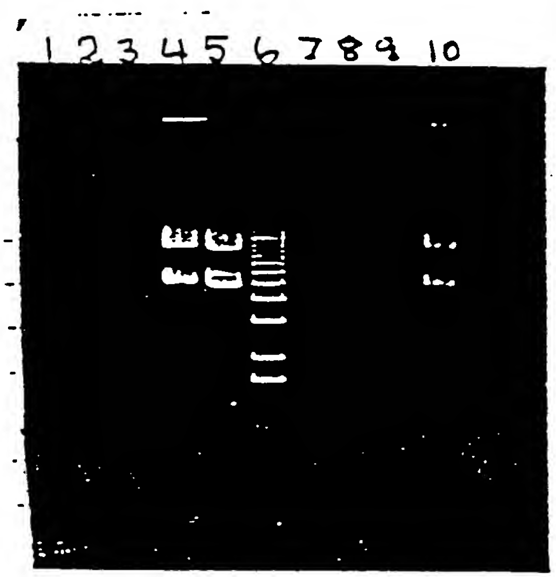
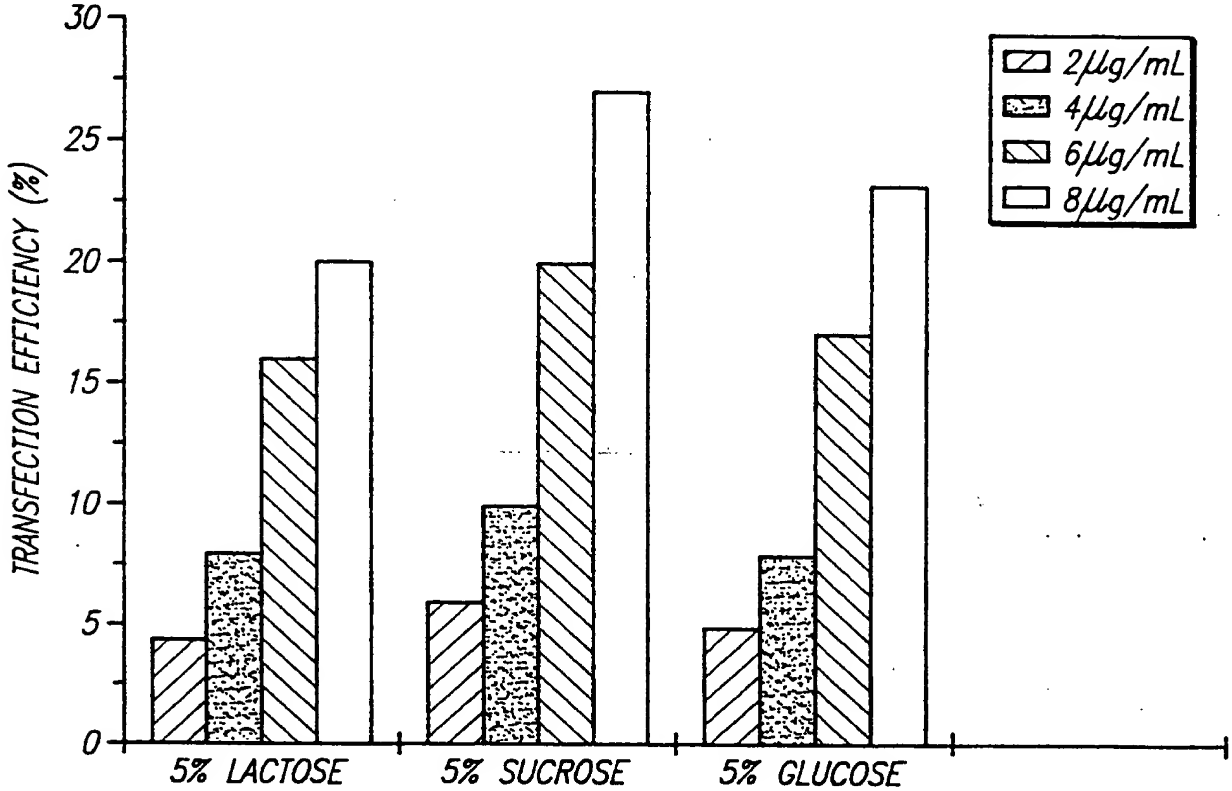


FIG. 7


2μg/mL
4μg/mL
6μg/mL
8μg/mL
TRANSFECTION EFFICIENCY (%)
30
25
20
15
10
5
0
5% LACTOSE
5% SUCROSE
5% GLUCOSE

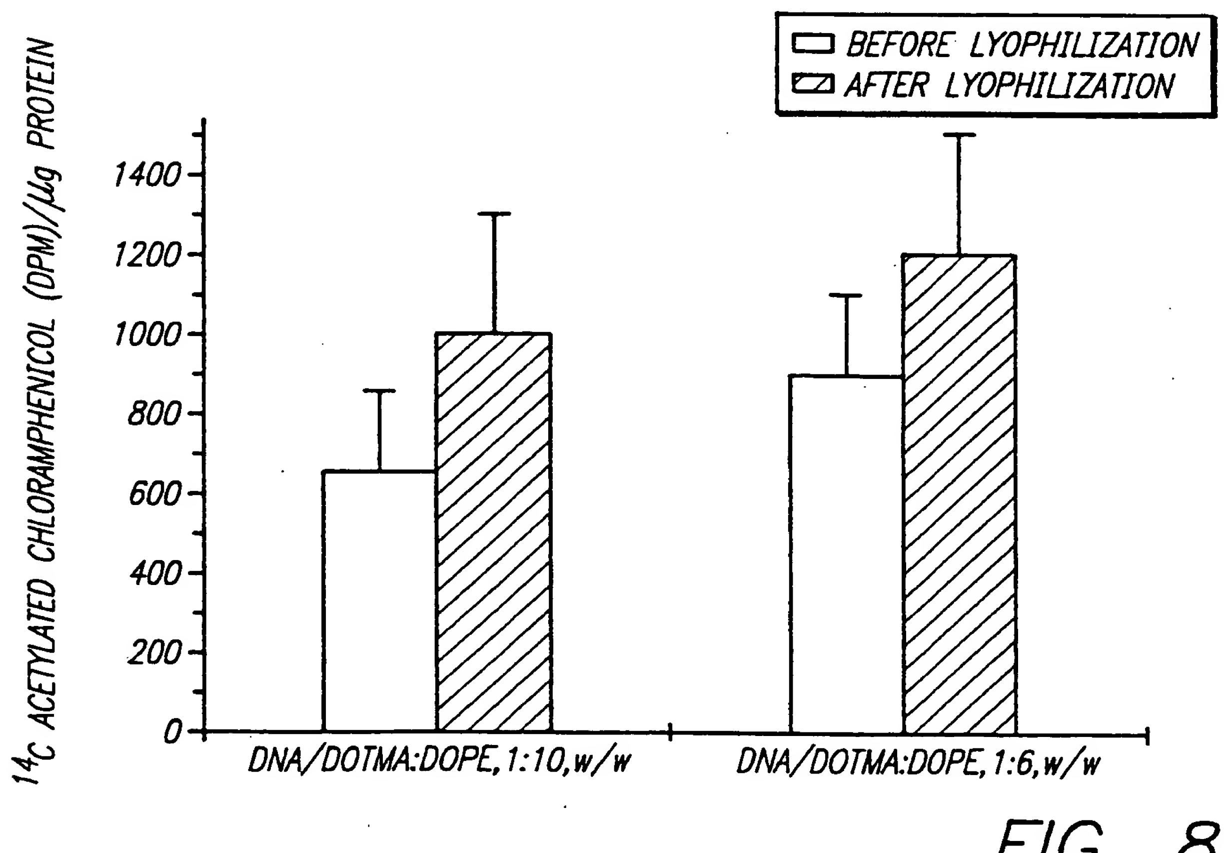
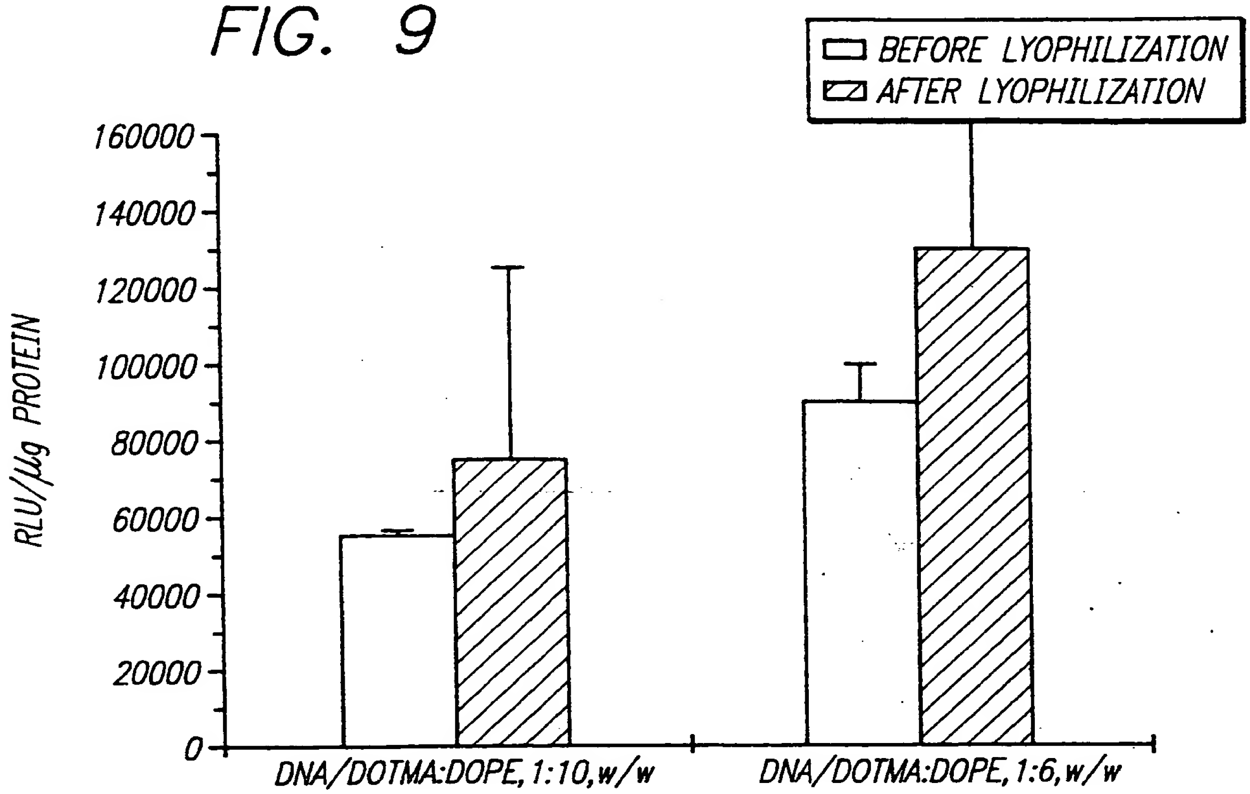

BEFORE LYOPHILIZATION
AFTER LYOPHILIZATION
14C ACETYLATED CHLORAMPHENICOL (DPM)/μg PROTEIN
1400
1200
1000
800
600
400
200
0
DNA/DOTMA:DOPE,1:10,w/w
DNA/DOTMA:DOPE,1:6,w/w

FIG. 8

FIG. 9


BEFORE LYOPHILIZATION
AFTER LYOPHILIZATION
160000
140000
120000
100000
80000
60000
40000
20000
0
RLU/μg PROTEIN
DNA/DOTMA:DOPE, 1:10, w/w
DNA/DOTMA:DOPE, 1:6, w/w

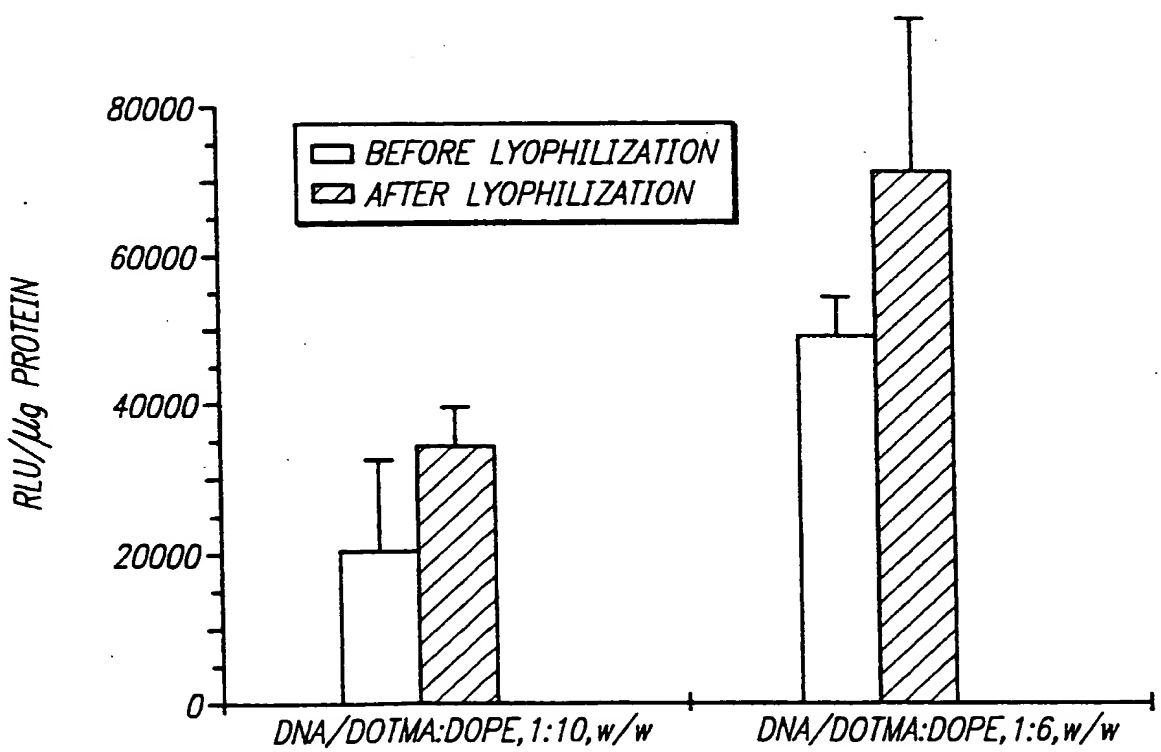

BEFORE LYOPHILIZATION
AFTER LYOPHILIZATION
80000
60000
40000
20000
0
RLU/μg PROTEIN
DNA/DOTMA:DOPE, 1:10, w/w
DNA/DOTMA:DOPE, 1:6, w/w

FIG. 10

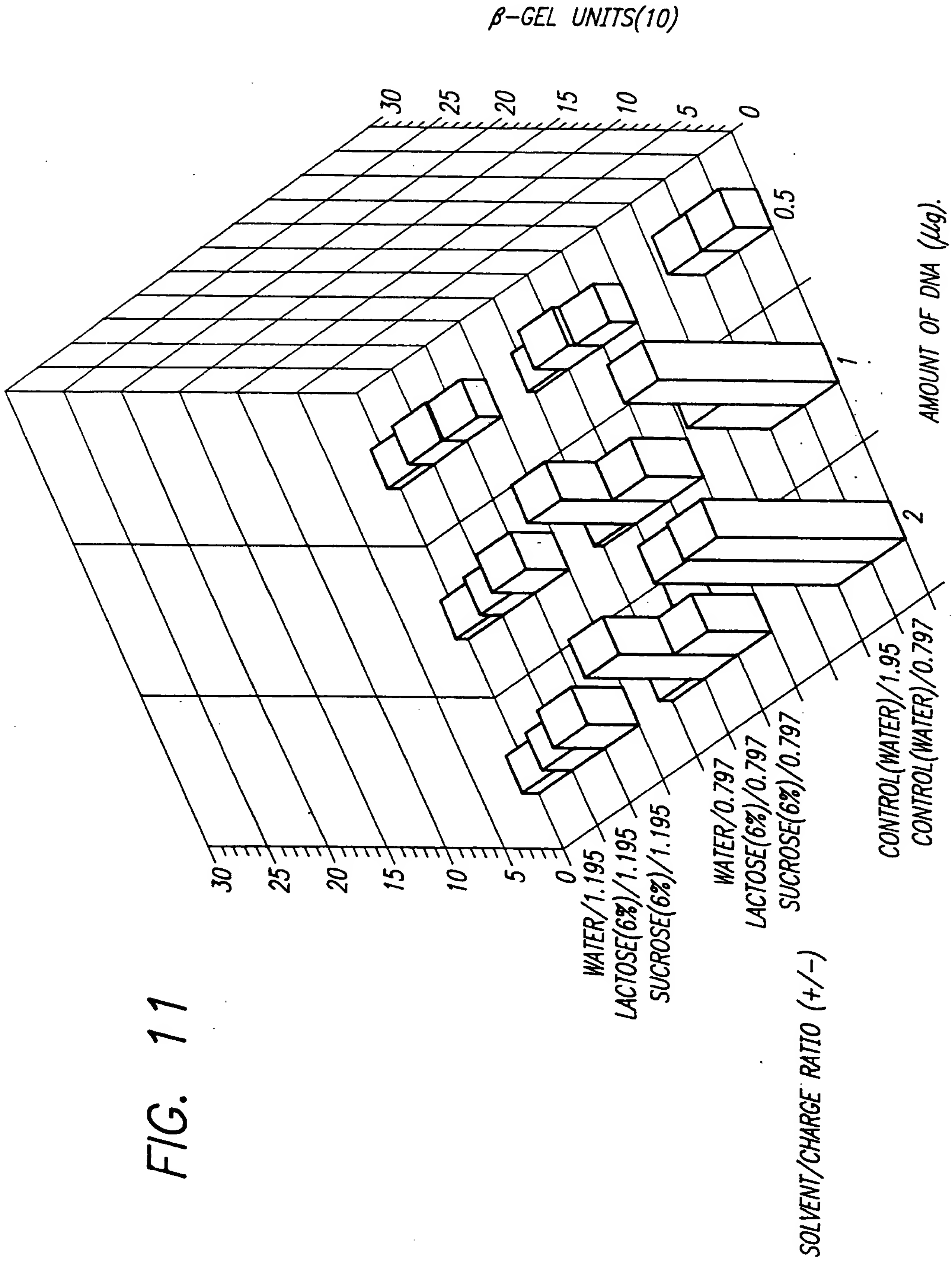

β-GEL UNITS(10)
30
25
20
15
10
5
0
0.5
1
2
AMOUNT OF DNA (μg).
30
25
20
15
10
5
0
WATER/1.195
LACTOSE(6%)/1.195
SUCROSE(6%)/1.195
WATER/0.797
LACTOSE(6%)/0.797
SUCROSE(6%)/0.797
CONTROL(WATER)/1.95
CONTROL(WATER)/0.797
SOLVENT/CHARGE RATIO (+/-)

FIG. 11

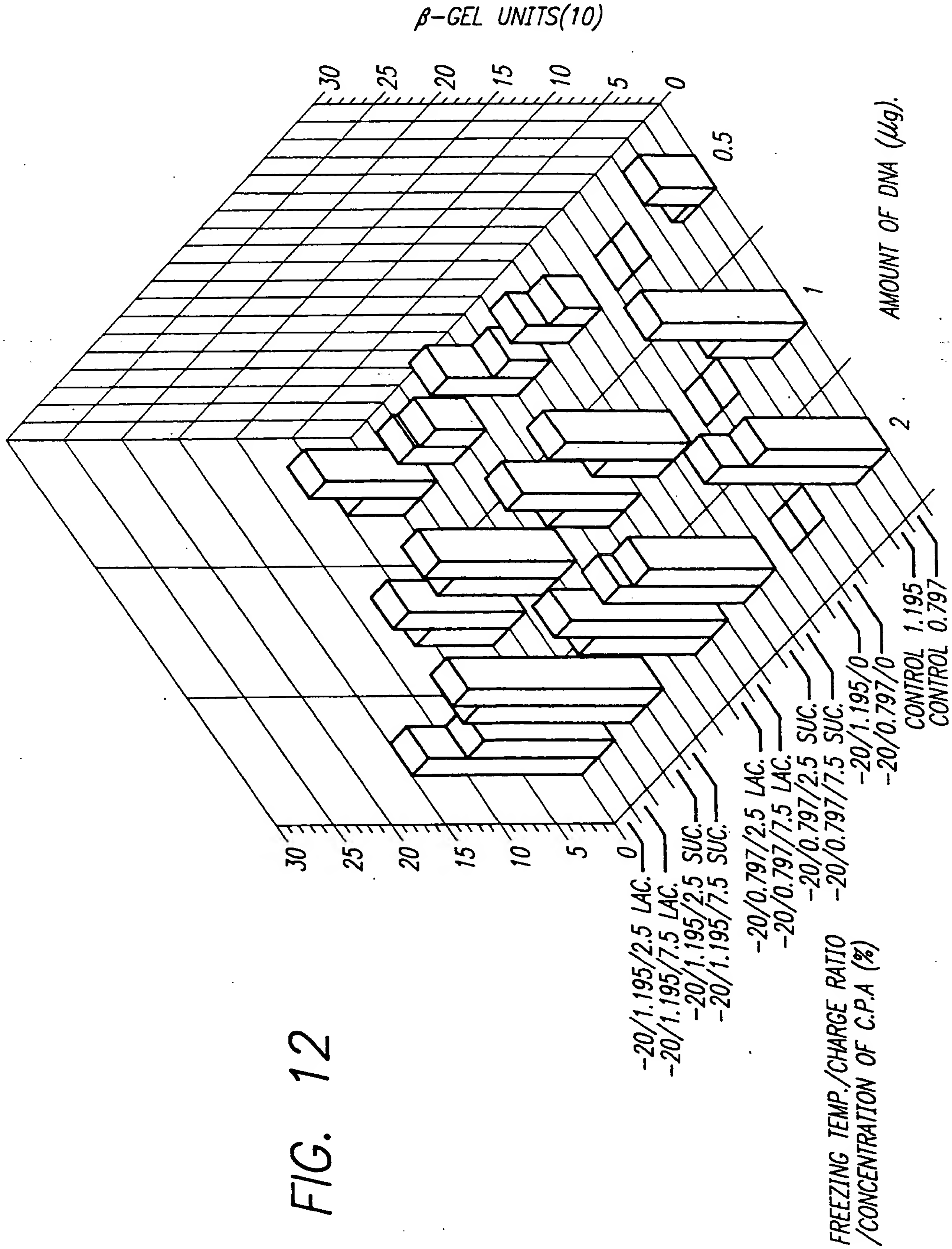

β-GEL UNITS(10)
30
25
20
15
10
5
0
0.5
1
2
AMOUNT OF DNA (μg).
-20/1.195/2.5 LAC.
-20/1.195/7.5 LAC.
-20/1.195/2.5 SUC.
-20/1.195/7.5 SUC.
-20/0.797/2.5 LAC.
-20/0.797/7.5 LAC.
-20/0.797/2.5 SUC.
-20/0.797/7.5 SUC.
-20/1.195/0
-20/0.797/0
CONTROL 1.195
CONTROL 0.797
FREEZING TEMP./CHARGE RATIO
/CONCENTRATION OF C.P.A (%)

FIG. 12

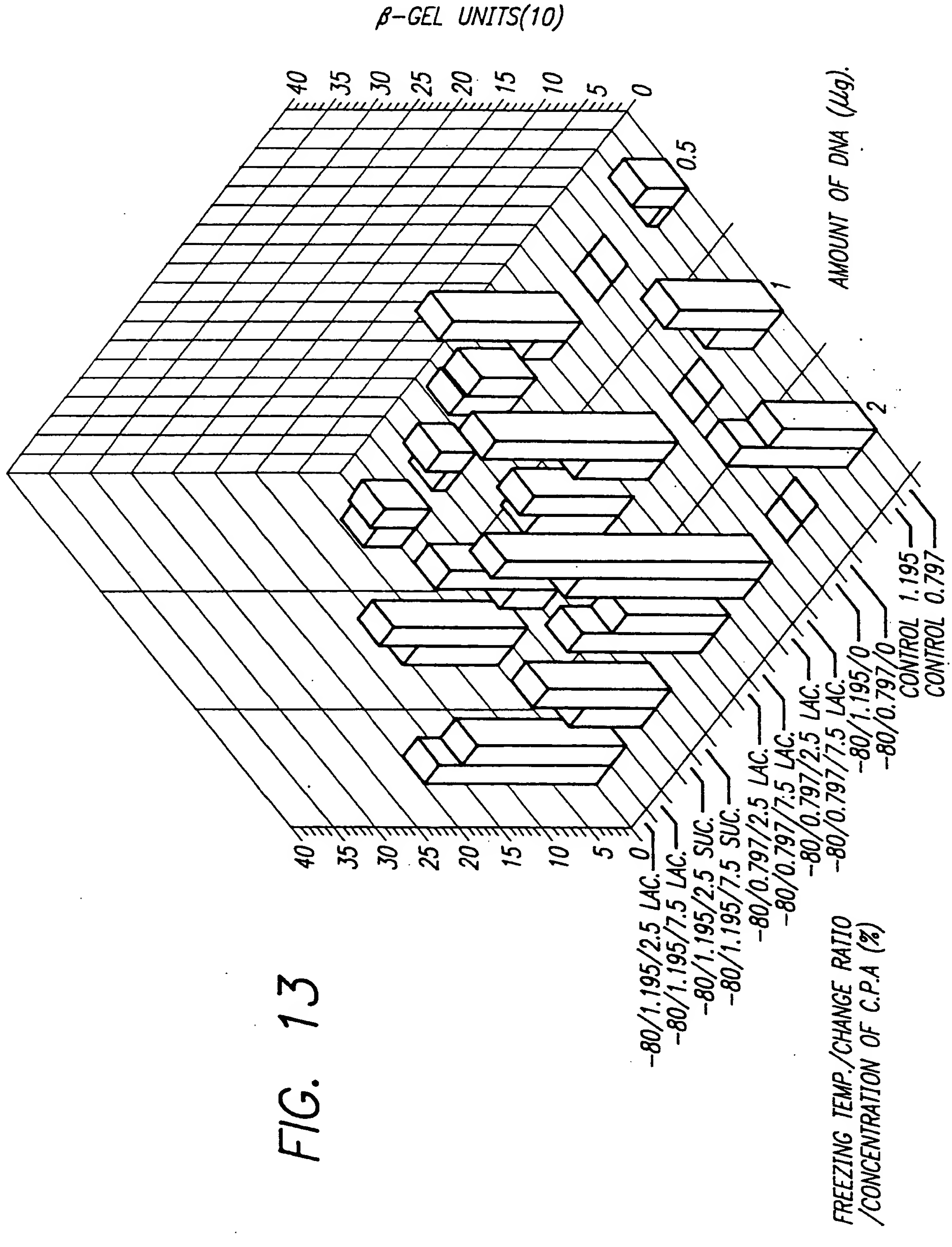
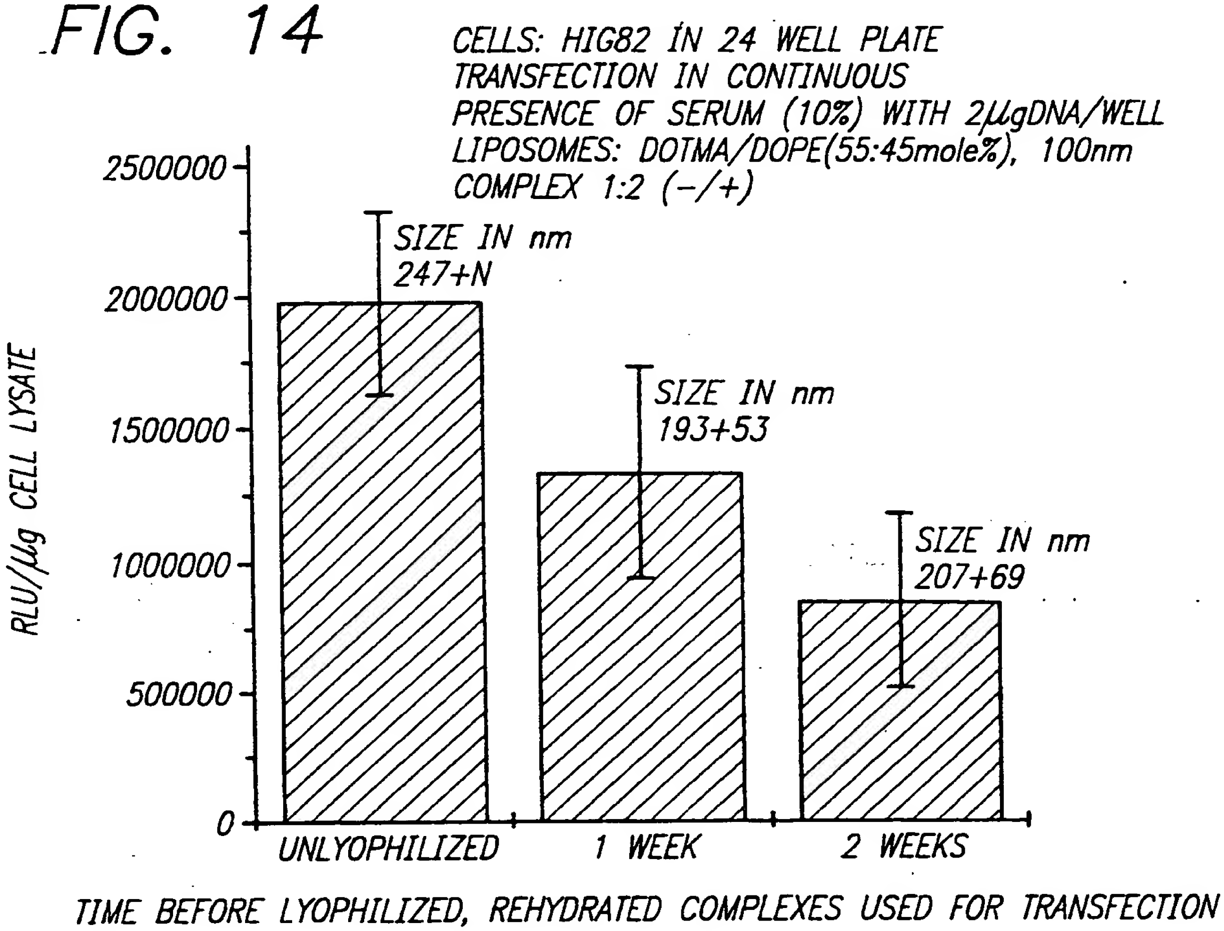

β-GEL UNITS(10)
40 35 30 25 20 15 10 5 0
AMOUNT OF DNA (μg).
0.5
1
2
CONTROL 1.195
CONTROL 0.797
-80/1.195/2.5 LAC.
-80/1.195/7.5 LAC.
-80/1.195/2.5 SUC.
-80/1.195/7.5 SUC.
-80/0.797/2.5 LAC.
-80/0.797/7.5 LAC.
-80/0.797/2.5 LAC.
-80/0.797/7.5 LAC.
-80/1.195/0
-80/0.797/0
FREEZING TEMP./CHANGE RATIO
/CONCENTRATION OF C.P.A (%)

FIG. 13

FIG. 14


CELLS: HIG82 IN 24 WELL PLATE
TRANSFECTION IN CONTINUOUS
PRESENCE OF SERUM (10%) WITH 2μgDNA/WELL
LIPOSOMES: DOTMA/DOPE(55:45mole%), 100nm
COMPLEX 1:2 (−/+)
RLU/μg CELL LYSATE
2500000
2000000
1500000
1000000
500000
0
SIZE IN nm
247+N
SIZE IN nm
193+53
SIZE IN nm
207+69
UNLYOPHILIZED
1 WEEK
2 WEEKS
TIME BEFORE LYOPHILIZED, REHYDRATED COMPLEXES USED FOR TRANSFECTION

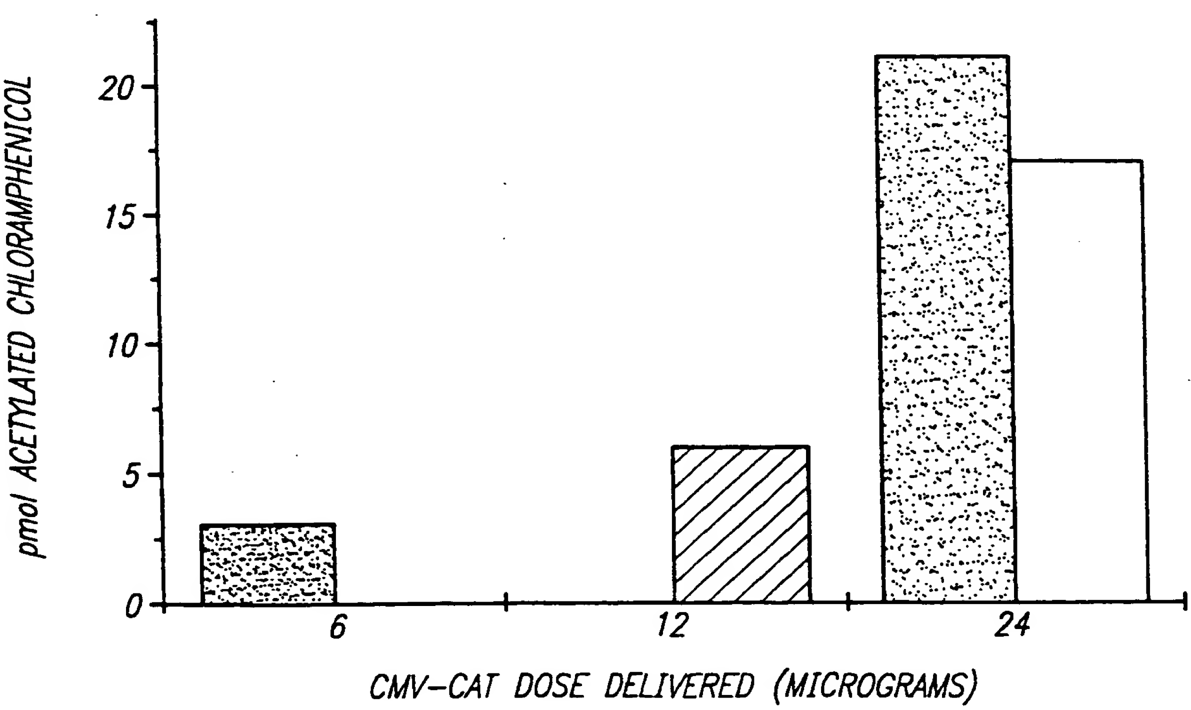

pmol ACETYLATED CHLORAMPHENICOL
20
15
10
5
0
6
12
24
CMV-CAT DOSE DELIVERED (MICROGRAMS)

FIG. 18

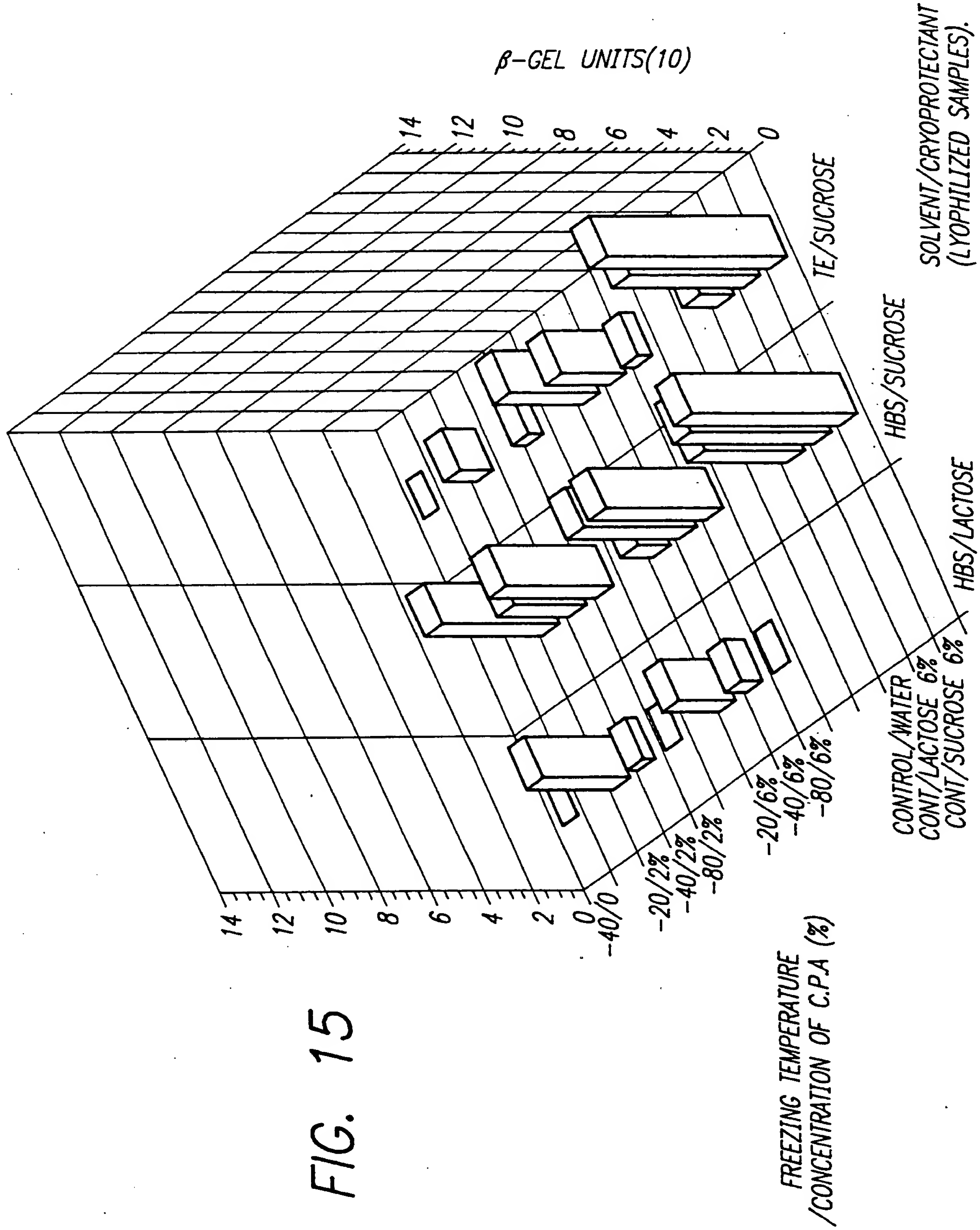

β-GEL UNITS(10)
14
12
10
8
6
4
2
0
SOLVENT/CRYOPROTECTANT (LYOPHILIZED SAMPLES).
TE/SUCROSE
HBS/SUCROSE
HBS/LACTOSE
-40/0
-20/2%
-40/2%
-80/2%
-20/6%
-40/6%
-80/6%
CONTROL/WATER
CONT/LACTOSE 6%
CONT/SUCROSE 6%
FREEZING TEMPERATURE /CONCENTRATION OF C.P.A (%)

FIG. 15

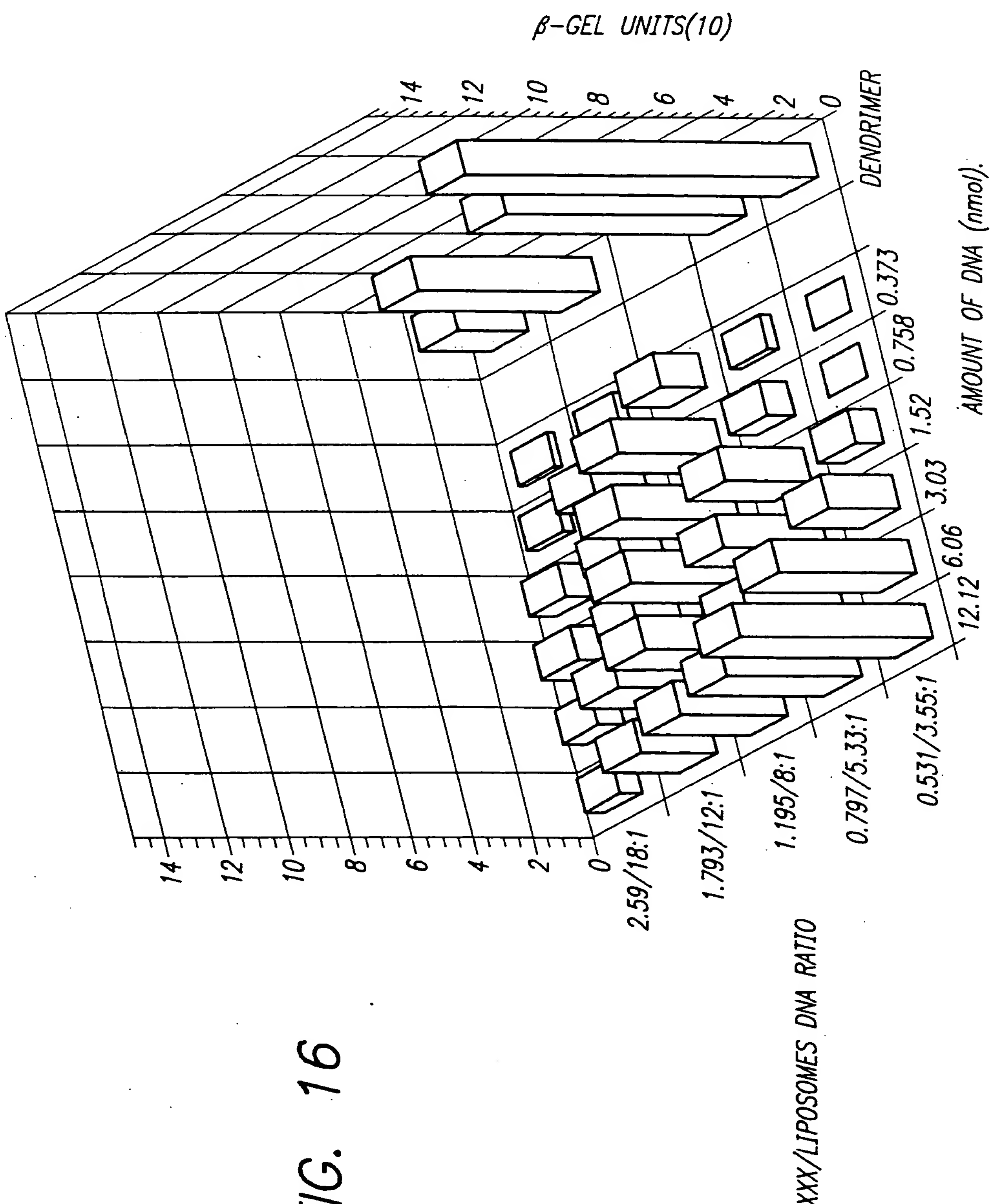

β-GEL UNITS(10)
0 2 4 6 8 10 12 14
DENDRIMER
0.373
0.758
1.52
3.03
6.06
12.12
AMOUNT OF DNA (nmol).
2.59/18:1
1.793/12:1
1.195/8:1
0.797/5.33:1
0.531/3.55:1
XXX/LIPOSOMES DNA RATIO

FIG. 16

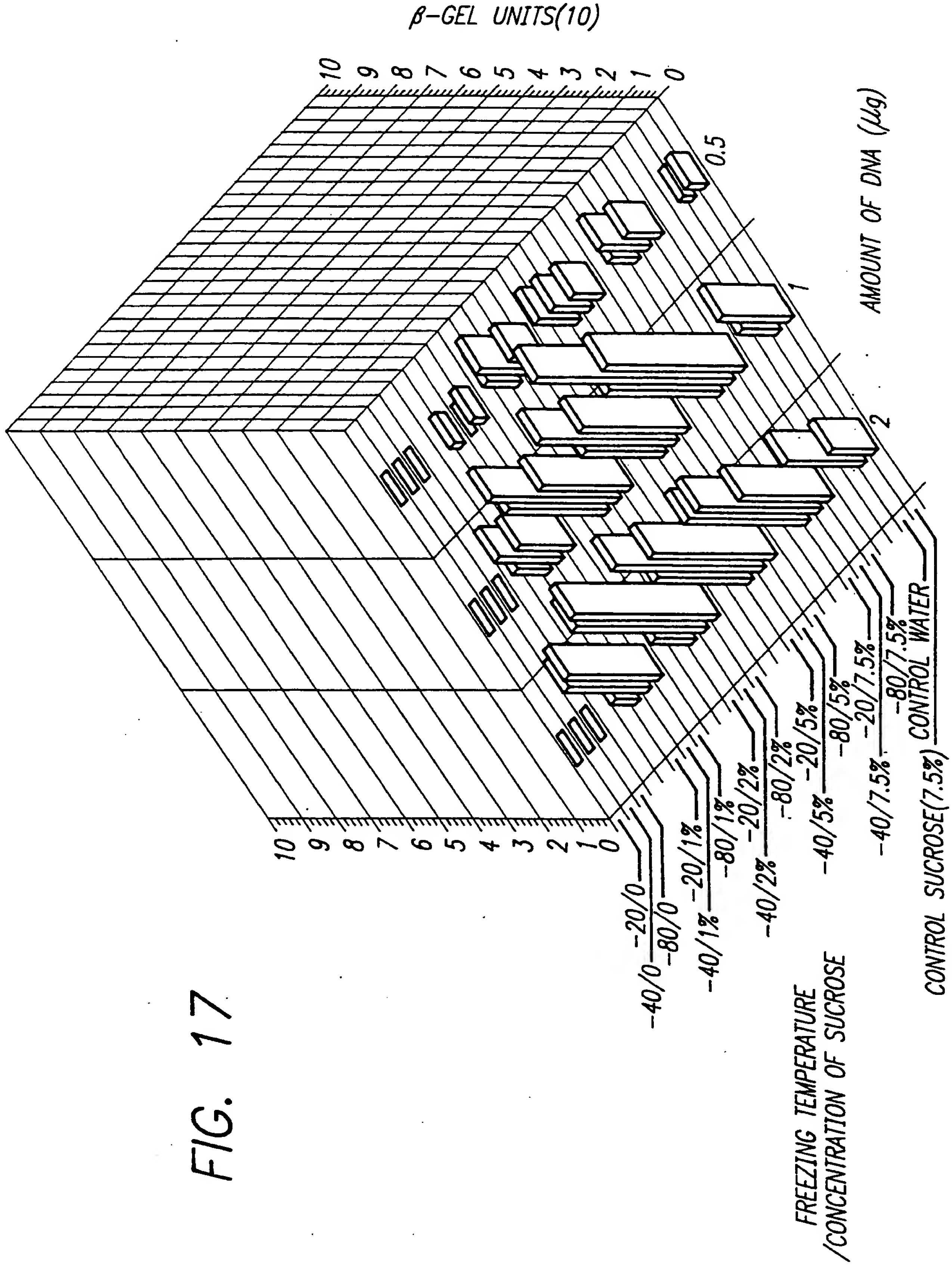

β-GEL UNITS(10)
0 1 2 3 4 5 6 7 8 9 10
AMOUNT OF DNA (μg)
0.5
1
2
-40/0
-20/0
-80/0
-40/1%
-20/1%
-80/1%
-40/2%
-20/2%
-80/2%
-40/5%
-20/5%
-80/5%
-40/7.5%
-20/7.5%
-80/7.5%
CONTROL SUCROSE(7.5%)
CONTROL WATER
FREEZING TEMPERATURE
/CONCENTRATION OF SUCROSE

FIG. 17

FIG. 19

SPERMINE-5-CARBOXYGLYCINE (N′-STEARYL – N′-OLEYL) AMIDE TETRATRIFLUOROACETIC ACID SALT (JK-75)

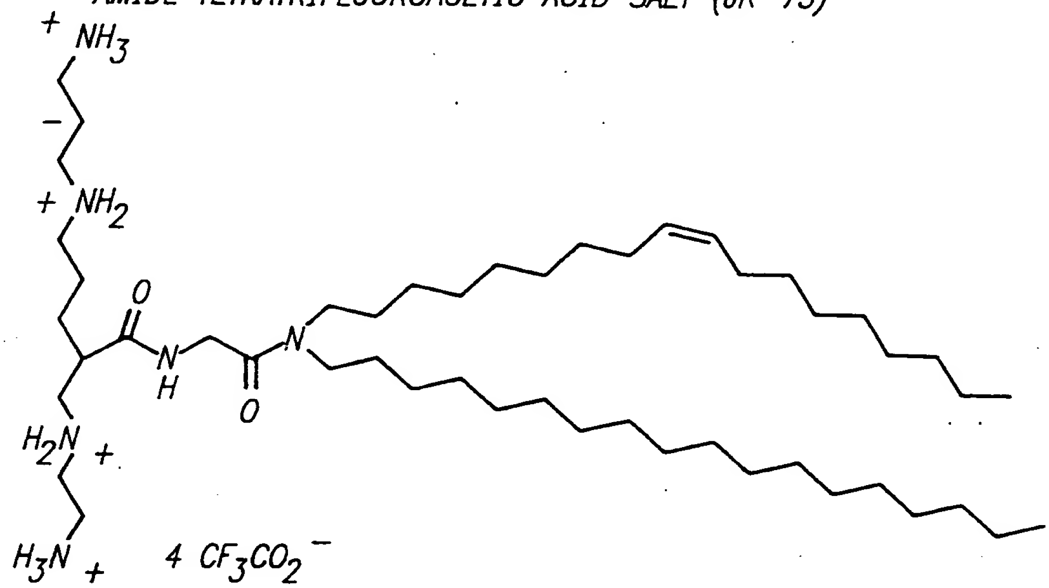
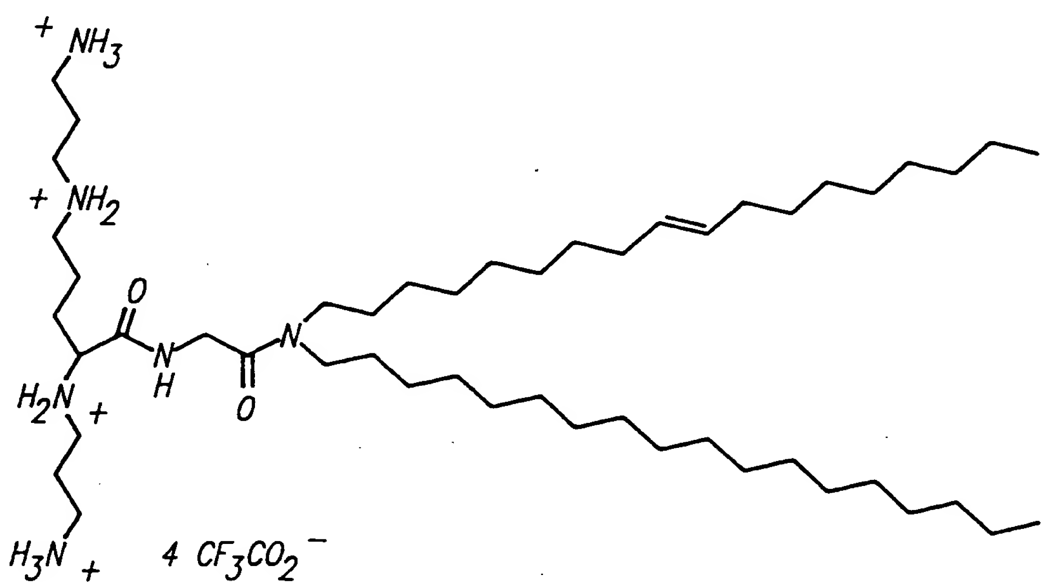


FIG. 20

SPERMINE-5-CARBOXYGLYCINE (N′-STEARYL- N′-ELAIDYL) AMIDE TETRATRIFLUOROACETIC ACID SALT (JK-76)



AGMATINYL CARBOXYCHOLESTEROL ACETIC ACID SALT (AG-Chol)

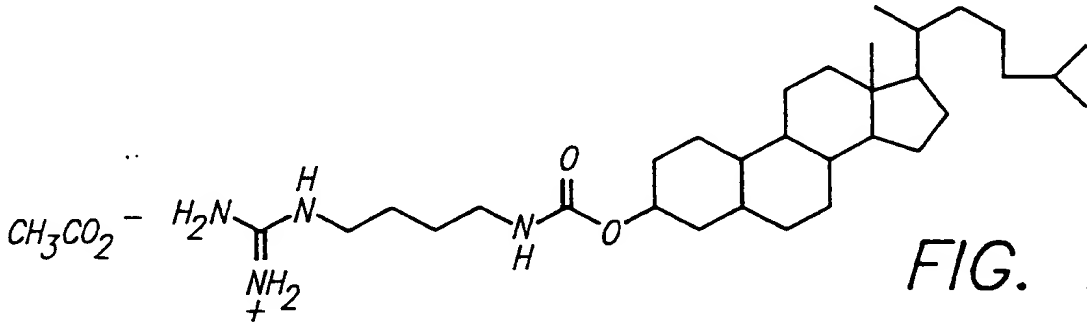


FIG. 21

SPERMINE-5-CARBOXY-β-ALANINE CHOLESTERYL ESTER TETRATRIFLUOROACETIC ACID SALT (CAS)

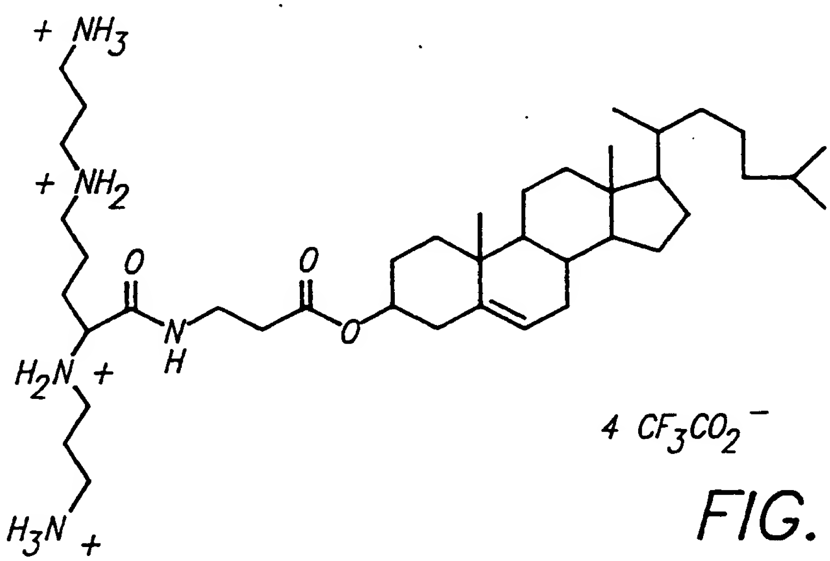


FIG. 22

2,6-DIAMINOHEXANOEYL β-ALANINE CHOLESTERYL ESTER BISTRIFLUOROACETIC ACID SALT (CAL)

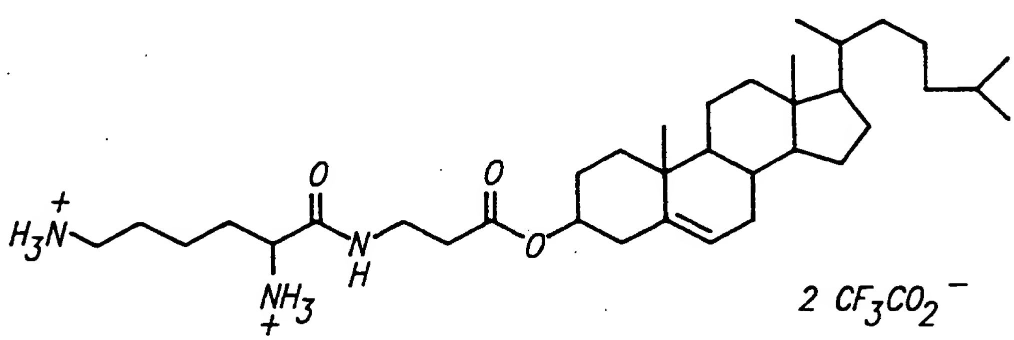
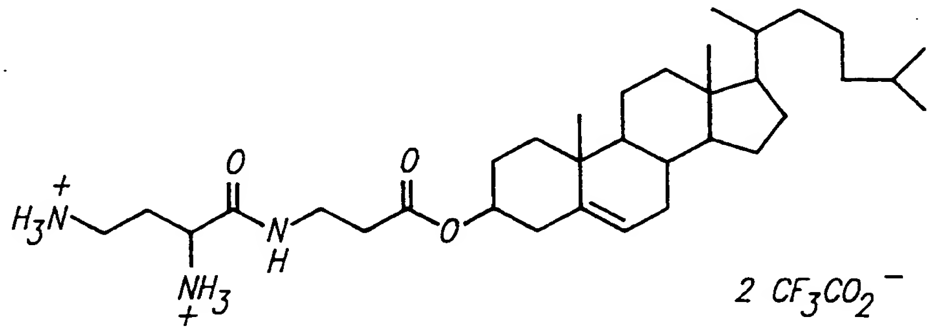


FIG. 23

FIG. 24

2,4-DIAMINOBUTYROYL β-ALANINE CHOLESTERYL ESTER BISTRIFLUOROACETIC ACID SALT (CAB)



N, N-Bis (3-AMINOPROPYL)-3-AMINOPROPIONYL β-ALANINE CHOLESTERYL ESTER TRISTRIFLUOROACETIC ACID SALT (CASD)

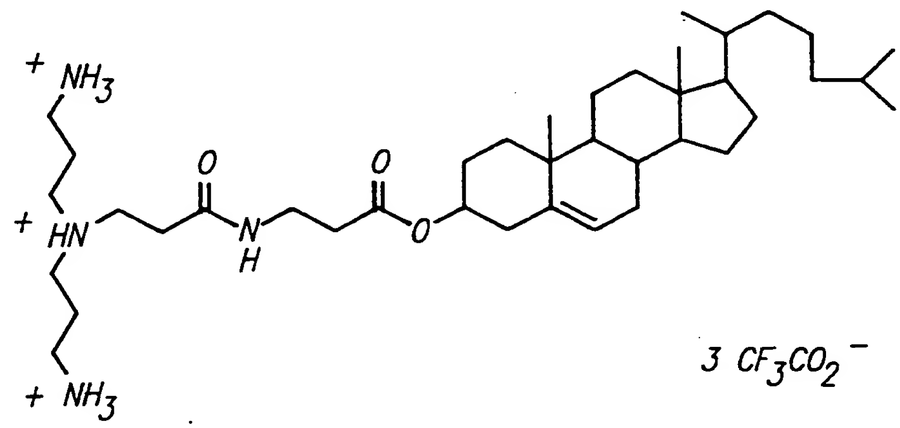


FIG. 25

[N, N-Bis(2-HYDROXYETHYL)-2-AMINOETHYL]AMINOCARBOXY CHOLESTERYL ESTER (JK-154)

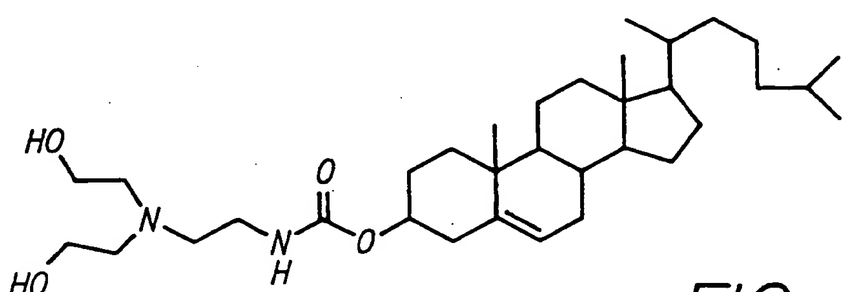


FIG. 26

CARNITINE ESTER LIPIDS

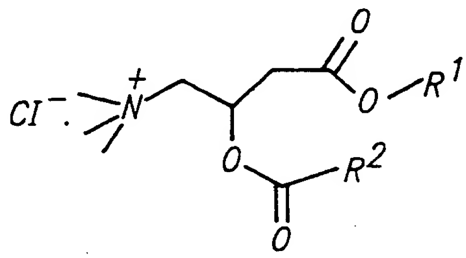
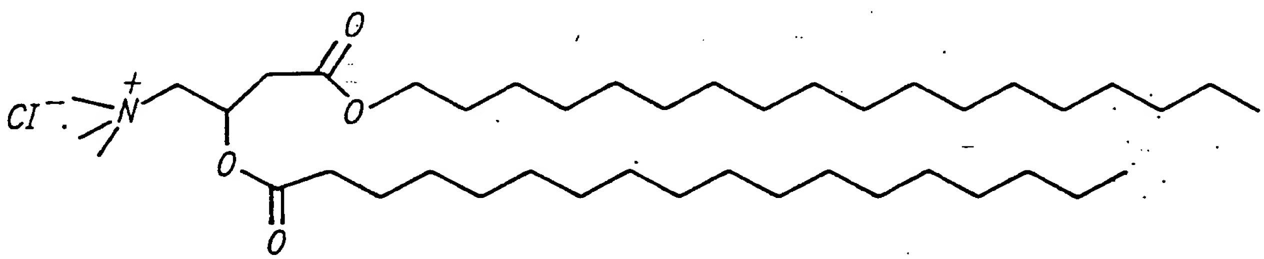


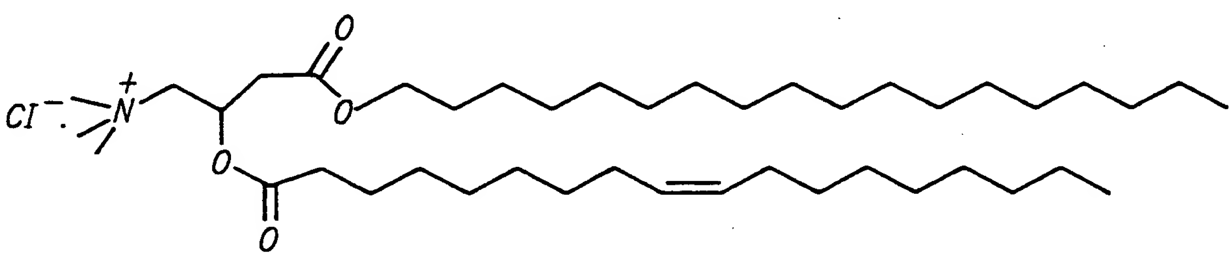
FIG. 27

$R^1=(CH_2)_aCH_3$ n=2 TO 30, 1 TO 6 UNSATURATED BONDS OR ISO CH_3 GROUPS

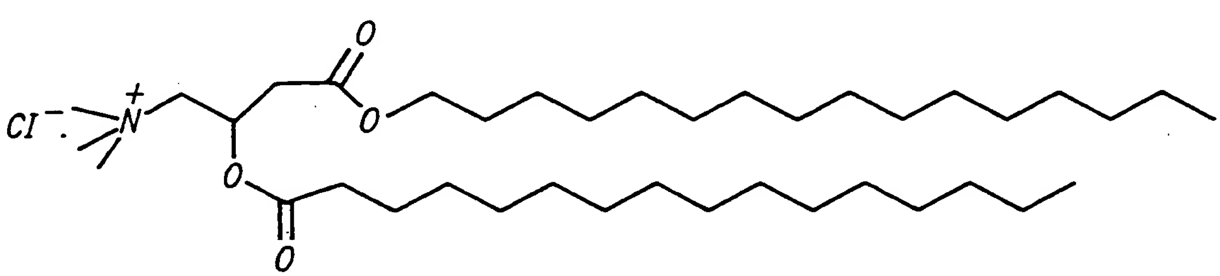
STEARYL STEAROYL CARNITINE ESTER CHLORIDE SALT (SSCE) FIG. 28



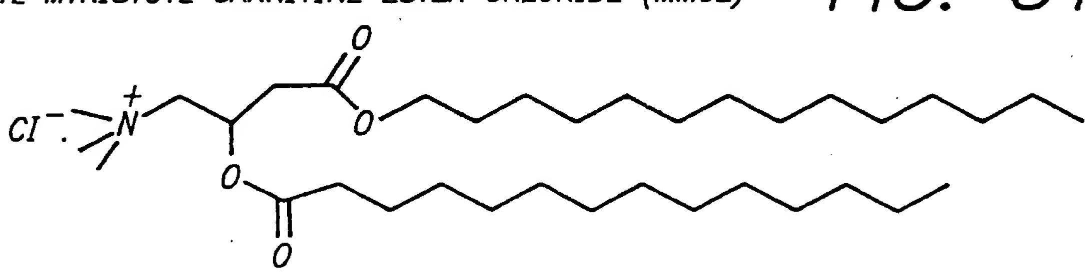
STEARYL OLEOYL CARNITINE ESTER CHLORIDE (SOCE) FIG. 29



PALMITYL PALMITOYL CARNITINE ESTER CHLORIDE (PPCE) FIG. 30



MYRISTYL MYRISTOYL CARNITINE ESTER CHLORIDE (MMCE) FIG. 31



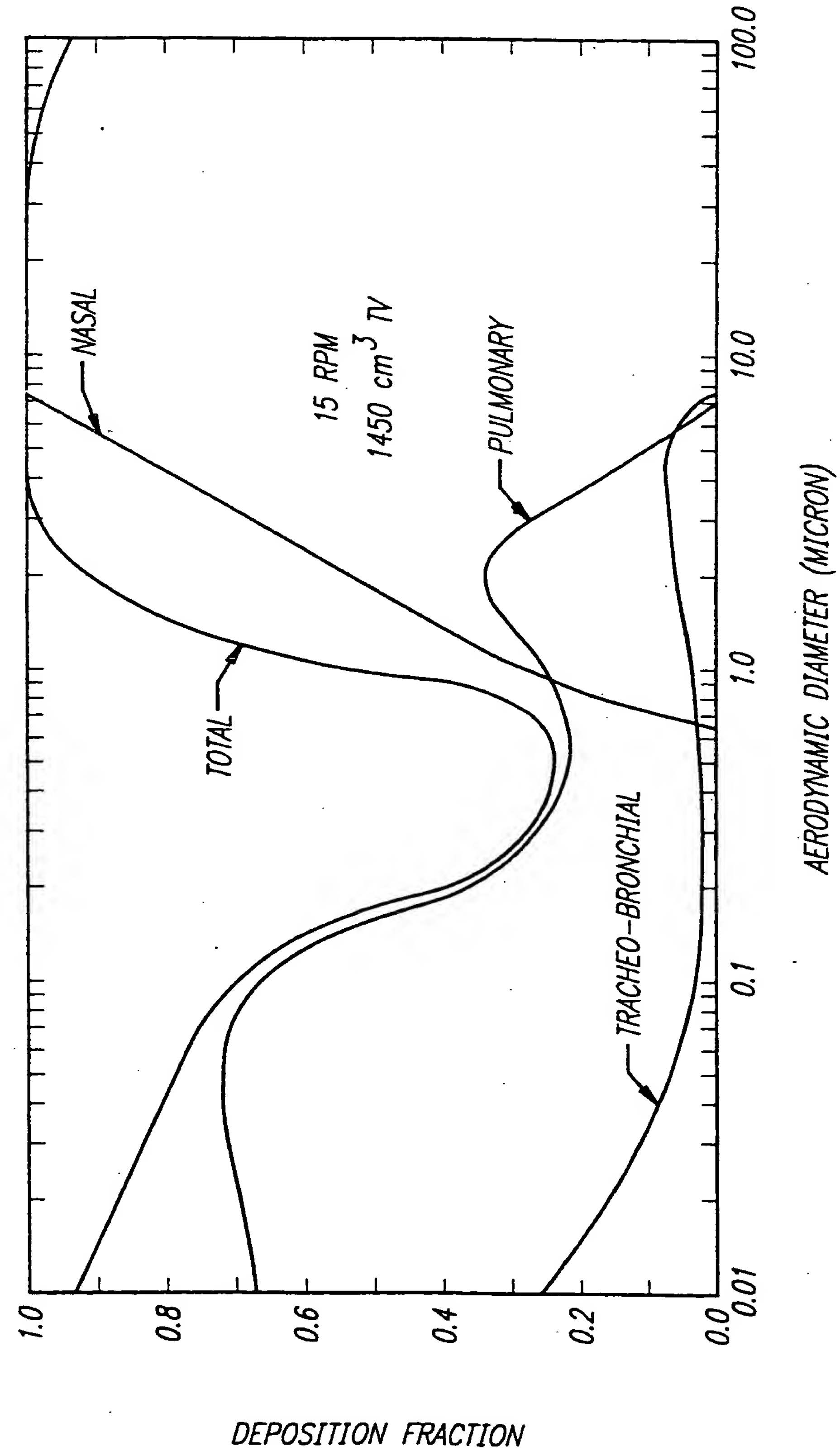

NASAL
15 RPM
1450 cm3 TV
PULMONARY
TOTAL
TRACHEO-BRONCHIAL
1.0
0.8
0.6
0.4
0.2
0.0
0.01
0.1
1.0
10.0
100.0
AERODYNAMIC DIAMETER (MICRON)
DEPOSITION FRACTION

FIG. 32

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/07867

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C12N 15/10, 15/11, 15/63
US CL :435/172.3; 536/23.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/172.3; 536/23.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, Dialog
search terms: lyophilization, transfection, transformation, DNA, polynucleotide, cryoprotectant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	FROBISHER et al., "FUNDAMENTALS OF MICROBIOLOGY", published 1974 by W. B. Saunders Company (Philadelphia), pages 280-282, see pages 280-282.	1-19 -------- 20
Y	Proceedings of the National Academy of Sciences USA, Volume 84, issued November 1987, Felgner et al., "Lipofection: A highly efficient, lipid-mediated DNA-transfection procedure", pages 7413-7417, see entire article.	20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
16 AUGUST 1996	04 OCT 1996
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHILIP W. CARTER Telephone No. (703) 308-0196